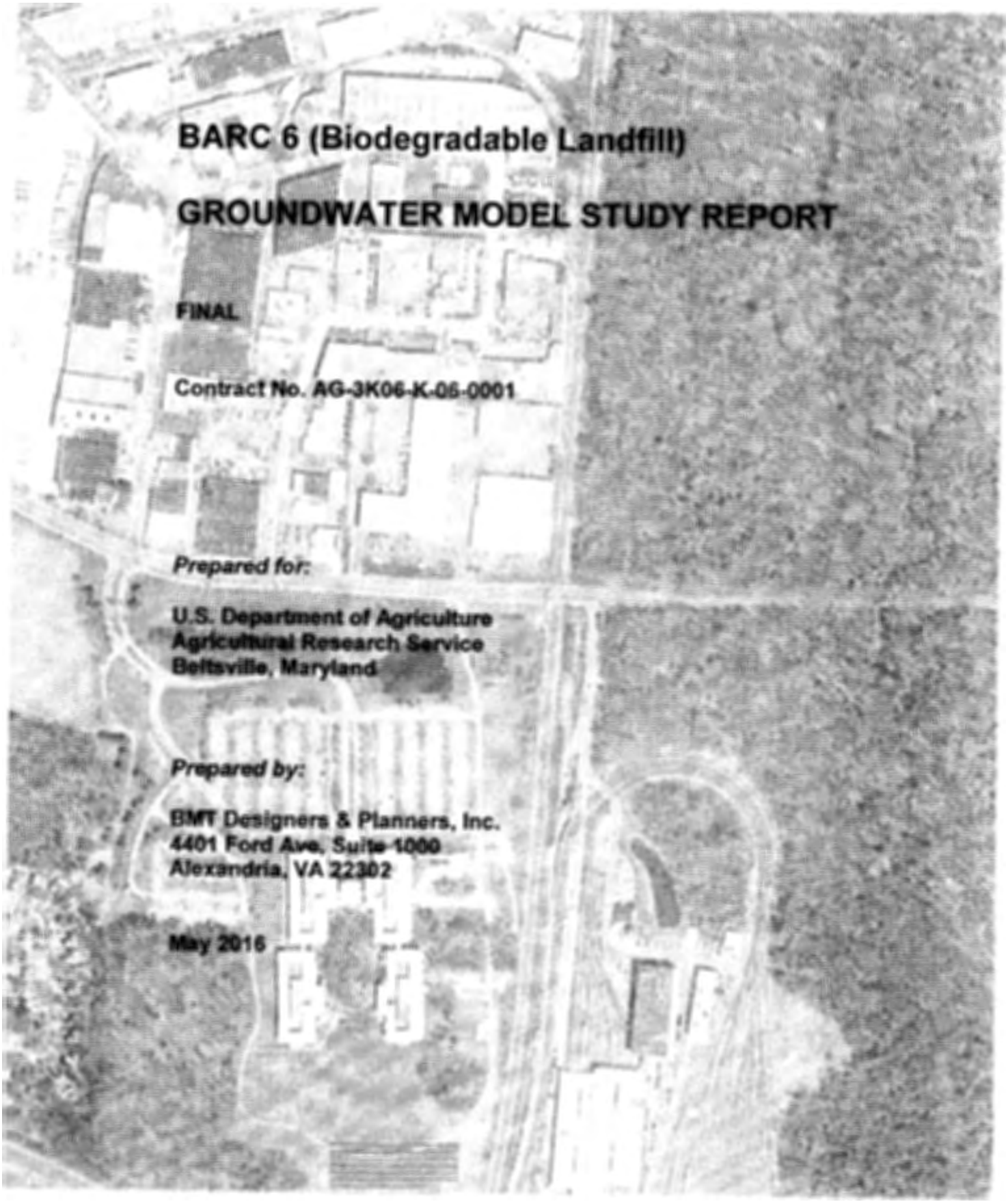

BARC 6 (Biodegradable Landfill)

GROUNDWATER MODEL STUDY REPORT

FINAL

Contract No. AG-3K06-K-06-0001

Prepared for:

U.S. Department of Agriculture
Agricultural Research Service
Beltsville, Maryland

Prepared by:

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May 2016

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LIST OF ACRONYMS

µg/L	microgram per liter (ppb)
AEC	Advantage Environmental Consultants, LLC
ARS	Agricultural Reasearch Service
AS	Air Sparging
AS/SVE	Air Sparging/Soil Vapor Extraction
BARC	Beltsville Agricultural Research Center
bgs	below ground surface
BMT	BMT Designers and Planners, Inc.
CERCLA	Comprehensive Environmental Response, Compensation, and Recovery Act
cfs	Cubic Feet per Second
CWA	Clean Water Act
DCE	Dichloroethene
DNAPL	Dense Non-Aqueous Phase Liquid
DO	Dissolved Oxygen
EPA	United States Environmental Protection Agency
foc	Fraction or Organic Carbon
FS	Feasibility Study
ft/ft	Foot per Foot
GWCC	USDA George Washington Carver Center
HRS	Hazard Ranking System
L/kg	Liters per kilogram
K_D	Soil Distribution Coefficient
K_F	Freundlich Constant
K_L	Langmuir Constant
Koc	Organic Carbon/Water Partition Cofficient
kg/m^3	Kilogram per Cubic Meter
MCL	Maximum Contaminant Limit
MDL	Method Detection Limit
MDE	Maryland Department of the Environment
mg/L	milligram per liter (ppm)
MNA	Monitored Natural Attenuation
MSL	Mean Sea Level
MT3D	Modular Transport, 3-Dimensions
MW	Monitoring Well
NCP	National Contingency Plan

LIST OF ACRONYMS

(Continued)

NIST	National Institute of Standards and Technology
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
ORP	Oxidation Reduction Potential
PCE	Tetrachloroethene
OSHA	Occupational Health and Safety Administration
PA/SI	Preliminary Assessment and Site Inspectoin
ppb	parts per billion
ppm	parts per million
rb	Bulk Density
RCRA	Resource Conservation and Recovery Act
RD	Remedial Design
RI	Remedial Investigation
RT3D	Reactive Transport IN 3-Dimensions
SVE	Soil Vapor Extraction
SWDA	Safe Water Drinking Act
TCE	Trichloroethene
TOC	Total Organic Carbon
TCLP	Toxicity Characterization Leaching Procedure
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VC	Vinyl Chloride
VCP	Voluntary Cleanup Program
VOC	Volatile Organic Compound
WMATA	Washington Metropolitan Area Transit Authority

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1. INTRODUCTION

The USDA-ARS operates the Beltsville Agricultural Research Center (BARC) in the northwestern portion of Prince Georges County, in Beltsville, Maryland. The BARC facility currently consists of more than 6,600 acres of agricultural fields, offices, and research laboratories. Due to historical operational practices, a number of areas within the BARC complex were identified as being of environmental concern in the early 1990's.

One of these sites known as the Biodegradable Site, also known as the BARC 6 Area of Concern (AOC), is located south of the intersection of Sunnyside Avenue and the CSX rail line, east of the George Washington Carver Center (GWCC) and is now integrated into a rail yard operated by the Washington Metropolitan Area Transit Authority (WMATA). A map depicting the location of the Biodegradable Site within BARC and the Washington DC Metropolitan Area is presented in Figure 1.1.

1.1 Site History

The Biodegradable Site has been extensively investigated since the early 1990's. A chronology of those investigations has been provided in several reports, but notably the initial draft Remedial Investigation (RI) provides a complete discussion (BMT Entech, 2004). The historical discussion here is not intended to be comprehensive; rather, it is intended to provide sufficient context for the studies described in this report.

The Biodegradable Site is bordered on the north, east, and south by the non-tidal wetlands of Indian Creek. Groundwater within the wetlands is at or near the surface and flows towards Indian Creek to the southeast. Approximately 4 acres in size, the Biodegradable Site was used as a landfill that was in operation from the 1940s until approximately 1975 (Entech, 1997). The former landfill operations at the site partially filled in the wetlands.

The Biodegradable Site was first identified as an area of environmental concern during a Phase I Environmental Site Assessment (ESA) completed in 1990. A Preliminary Assessment and Site Inspection (PA/SI) were conducted subsequent to the ESA, and documented the site to be a general refuse disposal area (Apex, 1991). Phase I and Phase II field investigations (Apex, 1990 and Apex, 1993) were performed to assess the presence of contamination associated with the former landfill (Figure 1.2).

Employees stated that a variety of wastes were disposed of at this landfill including wire, concrete, metal scrap, soils, glassware, office furniture, grass clippings and other "junk" (ENTECH, 1997a). A review of historical aerial photographic coverage of the Biodegradable Site revealed that disposal activity occurred at this site as early as 1943, and continued throughout the 1950s, 1960s, and 1970s (ENTECH, 1997b).

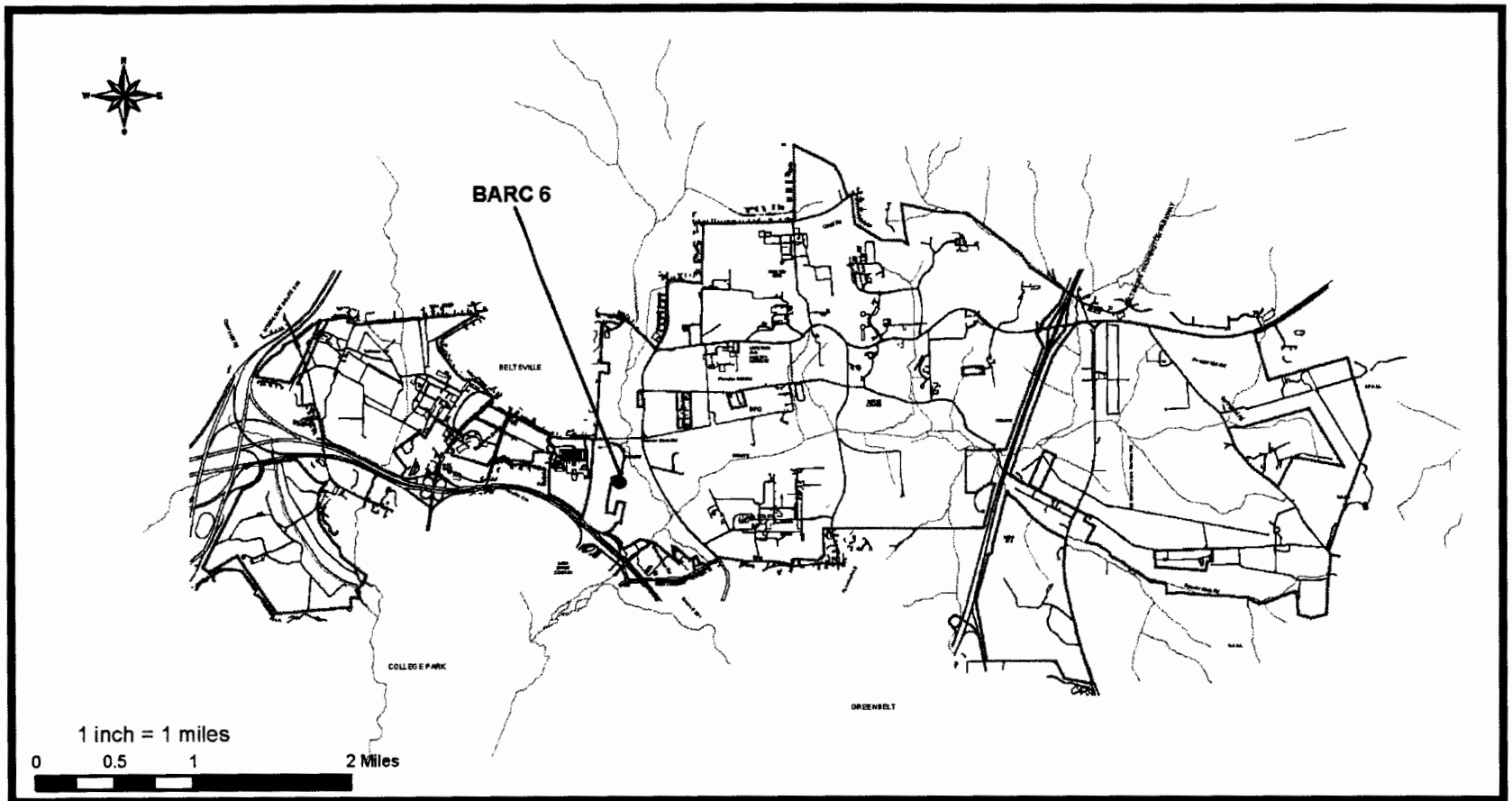


Figure 1.1

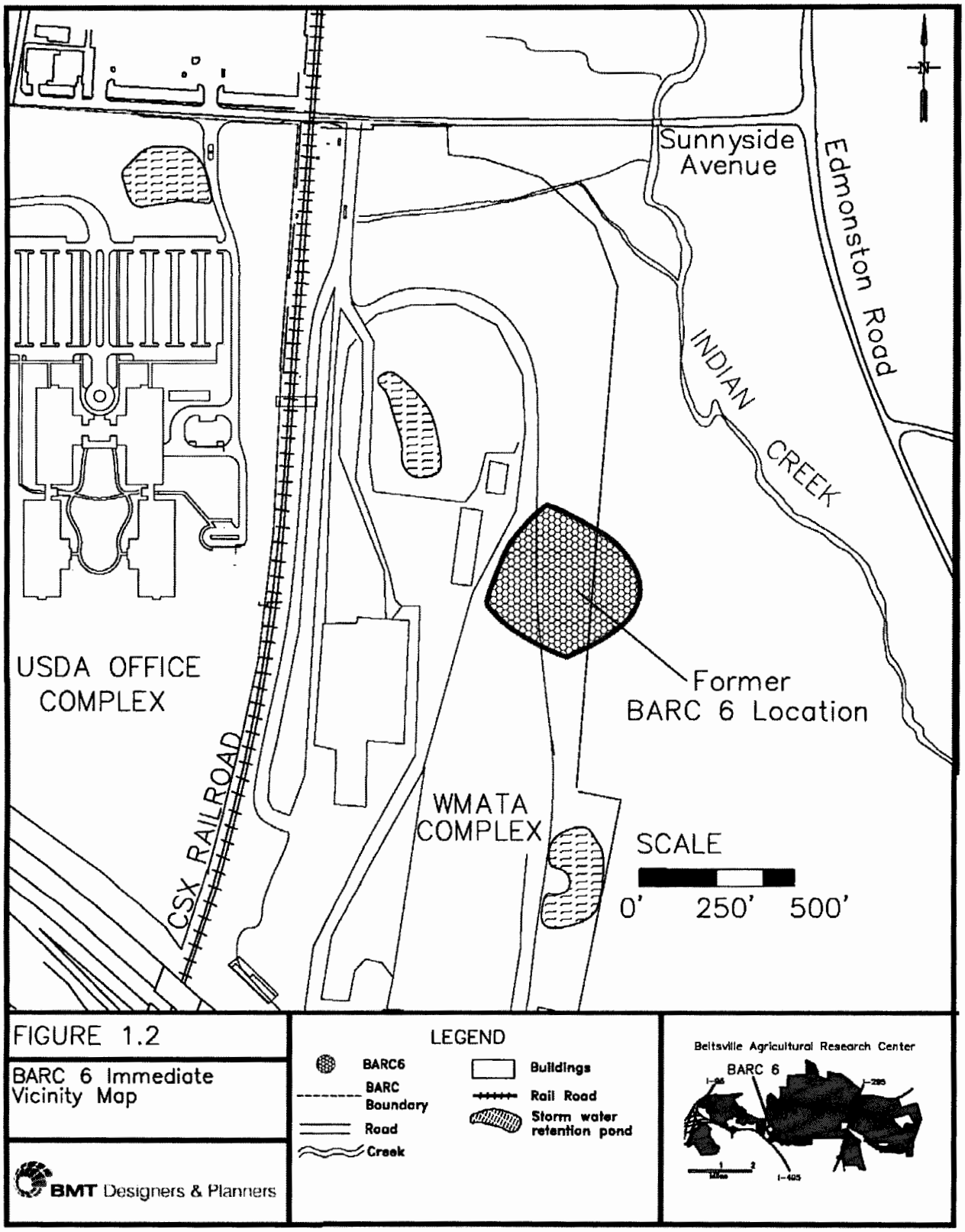
Biodegradable Site (BARC 6)
Location of BARC 6 within the
Beltsville Agricultural Research Center

BMT Designers & Planners

LEGEND

- BARC 6
- BARC Boundary
- Streams
- Roads

Location of Beltsville Agricultural Research Center (BARC)
in Prince George's County, Maryland


Sunnyside Avenue
Edmonston Road
INDIAN CREEK
USDA OFFICE COMPLEX
Former BARC 6 Location
CSX RAILROAD
WMATA COMPLEX
SCALE
0' 250' 500'
FIGURE 1.2
BARC 6 Immediate Vicinity Map
BMT Designers & Planners
LEGEND
BARC6
BARC Boundary
Road
Creek
Buildings
Rail Road
Storm water retention pond
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495

These initial studies identified a variety of contaminants in soil, sediment, surface water, and groundwater associated with the site. In 1992, EPA Region III conducted a Hazard Ranking System (HRS) scoring of BARC using the Biodegradable Site findings through that time frame. That analysis found that hazardous wastes containing "polyaromatic hydrocarbons, several pesticides, PCBs, 1,1,1-trichloroethane, trichloroethene, xylenes, arsenic, barium, beryllium, copper, lead, manganese, mercury, nickel, and zinc" had been disposed at the site. Further, the HRS scoring implicated the Biodegradable Site as "threatening the wetlands adjacent to Beaverdam Creek", endangering bald eagle habitat and threatened plant species (EPA, 1993).

ARS subsequently completed a major removal action in 1993 involving the excavation and disposal of the entirety of the landfill (approximately 93,000 tons of soil and debris). Removed soil and debris was replaced with clean fill; however, BARC was proposed for inclusion on the National Priorities List (NPL) in May of 1993 as a result of the HRS scoring, and was formally added to the NPL in 1994. The placement of BARC on the NPL required BARC to conduct further investigations to characterize and remedy human and ecological risks associated with the contamination in accordance with the National Contingency Plan (NCP) and the Comprehensive Environmental Response Compensation and Recovery Act (CERCLA) (40 CFR Part 300). Within this time frame, the property was transferred to WMATA to build a rail maintenance facility; however, ARS has retained full responsibility for addressing environmental concerns.

Although the other contaminants identified above were part of the HRS scoring, the primary concern quickly focused on the presence of volatile organic compounds (VOCs), especially the chlorinated aliphatic hydrocarbons (CAHs) tetrachloroethene (PCE) and trichloroethene (TCE) in the groundwater system. As required by CERCLA and their Federal Facilities Agreement (FFA) with EPA Region III, ARS initiated further investigations at the Biodegradable Site in 1995 that included historical aerial photography, interviews with personnel working in the area, and the development of a comprehensive Remedial Investigation (RI). As part of those investigations, over 20 monitoring wells were installed to delineate the vertical and horizontal extent of groundwater contamination associated with the site. In addition, samples of other environmental media (i.e., soil, sediment, surface water) were collected and analyzed.

After ARS initiated investigations required by CERCLA, a nearby upgradient source of contamination was identified as the W.P. Ballard dry-cleaning outlet supplier (Ballard) which operated from 1965 to 1988. Bulk quantities of PCE were stored and distributed at the site, which is located approximately 3,500 feet northwest and hydraulically upgradient of the Biodegradable Site. In 1988 a release of several hundred gallons of PCE from an above ground storage tank was documented at the Ballard facility and reported to the Maryland Department of the Environment (MDE) (MDE, 2007). Long term episodic spillage is

suspected to have occurred over time prior to the reported release.

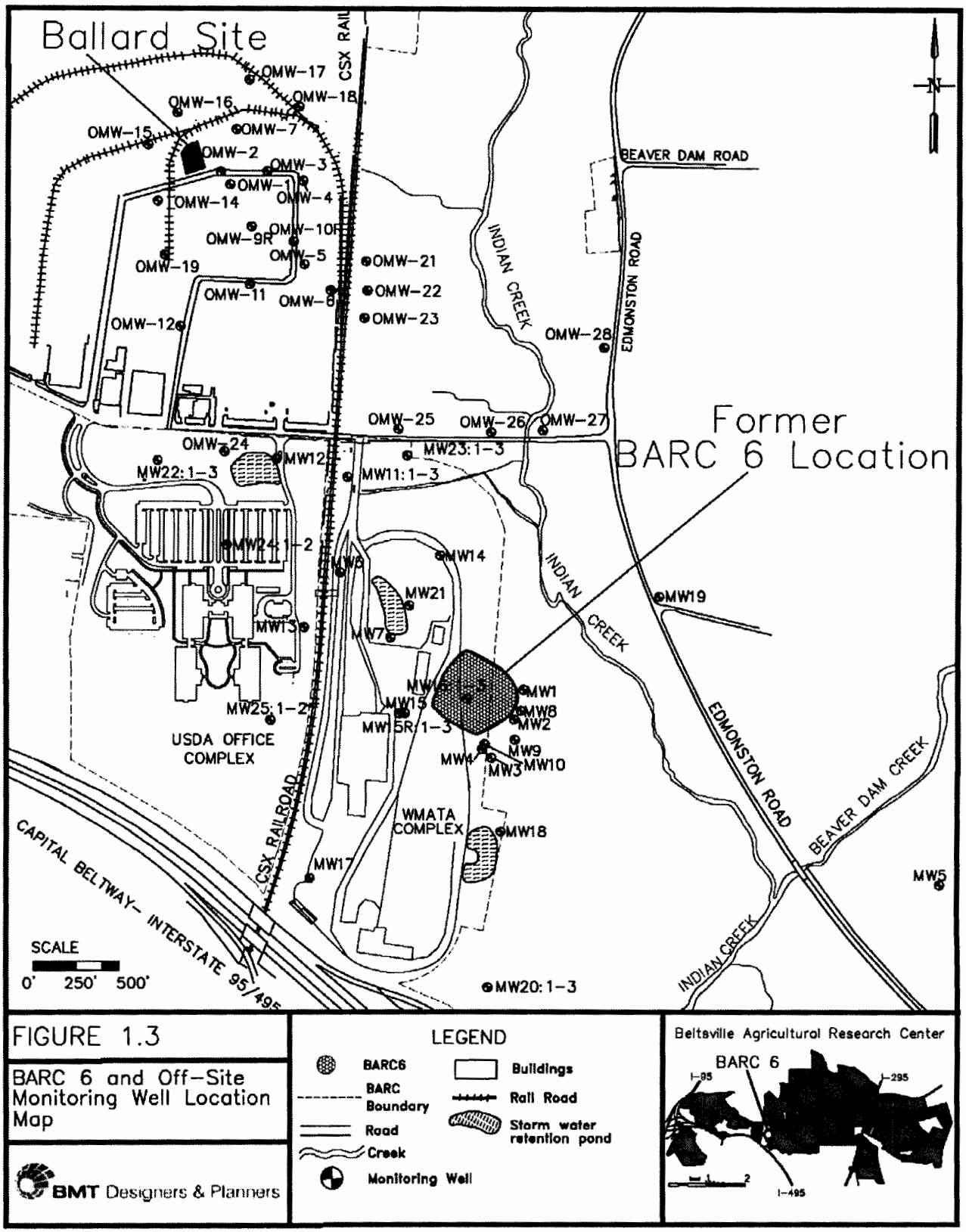
Groundwater contamination resulting from Ballard operations was not initially pursued by the MDE; however, discharges from the Ballard site became known, and beginning in 1999 the Ballard site entered the Voluntary Cleanup Program (VCP) administered by MDE. A map of the groundwater study area showing the location of the Ballard Property, the Biodegradable Site, and monitoring wells used to collect chemical data is shown in Figure 1.3.

Ballard installed and sampled monitoring wells on the property and in the vicinity to provide a supplemental source of groundwater data that includes spatial and temporal elements. Concentrations of PCE as high as 110,000 µg/L were detected in the groundwater underlying the Ballard Property. In 2002, Ballard began to implement a Subsurface Investigation Work Plan (AEC, 2002). This work plan included the installation and sampling of additional monitoring wells and the collection of additional groundwater samples using Geoprobe® methods. An air sparging/soil vapor extraction system was also installed in 2002, in accordance with this plan. The soil vapor extraction (SVE) system began operation in November of 2002, and the air sparging system began operation in February of 2003 (Miller, 2003). While these remedies have reduced concentrations of VOCs at the spill site, the systems have not fully addressed groundwater contamination at nearby properties.

1.2 Purpose

Data produced from the initial investigations completed from 1990 through 1992 were used to evaluate the Biodegradable Site for NPL purposes, and suggest that the Biodegradable Site was responsible for the observed groundwater contamination and potential effects to wetlands and sensitive environments. This data, however, was produced without the benefit of supplemental data from the Ballard facility that would have provided a more comprehensive area-wide indication of the source of groundwater contamination in the vicinity.

In addition, the considerable quantity of data that has been produced from the many years of subsequent investigations associated with the Biodegradable Site and Ballard sites suggest that the Biodegradable Site is not the source of VOCs detected in groundwater or, at least, not a primary source. In response to these investigations initiated at the Ballard site, a groundwater flow model was developed as part of the Remedial Investigation in 2004 to simulate the transport of PCE and TCE (BMT Entech, 2004). The 2004 groundwater model is discussed at greater length in Section 1.5; however, this initial effort did not include much of the data produced by Ballard. Based on the data, location, and hydrologic conditions, it appears that this extensive chlorinated solvent plume that has been associated with the Biodegradable Site is more likely the result of PCE discharges from the Ballard site.


Ballard Site
CSX RAIL
OMW-17
OMW-18
OMW-16
OMW-15
OMW-7
OMW-2
OMW-3
OMW-1
OMW-14
OMW-4
OMW-10R
OMW-9R
OMW-5
OMW-19
OMW-11
OMW-6
OMW-12
OMW-21
OMW-22
OMW-23
INDIAN CREEK
BEAVER DAM ROAD
EDMONSTON ROAD
OMW-28
OMW-25
OMW-26
OMW-27
Former
BARC 6 Location
OMW-24
MW12
MW23:1-3
MW22:1-3
MW11:1-3
MW24:1-2
MW6
MW14
MW21
MW19
MW13
MW7
MW1
MW15
MW8
MW2
MW15R:1-3
MW9
MW4
MW3
MW10
MW25:1-2
USDA OFFICE
COMPLEX
WMATA
COMPLEX
MW18
MW17
CSX RAILROAD
CAPITAL BELTWAY- INTERSTATE 95/495
BEAVER DAM CREEK
MW5
INDIAN CREEK
SCALE
0' 250' 500'
MW20:1-3
N
FIGURE 1.3
BARC 6 and Off-Site Monitoring Well Location Map
BMT Designers & Planners
LEGEND
BARC6
BARC Boundary
Road
Creek
Monitoring Well
Buildings
Rail Road
Storm water retention pond
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495

The purpose of this study is therefore to examine subsurface hydrogeologic conditions and characteristics, and the full record of groundwater data produced from the Biodegradable Site and Ballard investigations to determine likely origins of observed groundwater contamination.

1.3 Scope and Objectives

One effective way to evaluate contaminant movement in groundwater is to examine hydrogeologic conditions in the area, and use groundwater fate and transport modeling. The objective of this study is to develop a fate and transport model that accurately simulates spatial and temporal groundwater movement over time in the vicinity of the Biodegradable Site. Site-specific groundwater quality data in conjunction with subsurface geologic features, and contaminant (i.e., PCE and TCE) characteristics, are used in groundwater fate and transport modeling to show plume movement over time.

1.4 Computer Models

In order to address complex subsurface conditions, MODFLOW software was used to develop conceptual and groundwater fate and transport models in the immediate vicinity of the Biodegradable Site and the Ballard property. MODFLOW is a three dimensional finite-difference groundwater model that was developed by the United States Geological Survey (USGS), and is widely used and accepted within the scientific community. MODFLOW simulates groundwater flow under site specific conditions by calculating hydraulic potential within user-defined grid cells based on user defined criteria including: hydraulic conductivity, porosity and the presence of subsurface geologic confining layers. MODFLOW contains modules for the simulation of surface water features, rainfall, and evapotranspiration by surface vegetation and simulated engineering controls such as pumping wells.

MODFLOW supports several contaminant fate and transport models that work in concert with an integrated hydraulic modeling environment. The numerical reactive-transport three-dimensional (RT3D) model was used to simulate the transport and degradation of PCE and its degradation products or daughter compounds. RT3D was developed to simulate three-dimensional, multispecies and reactive transport of contaminants, and has been calibrated to simulate the transport and degradation of solvent plumes. Previous studies have demonstrated the use of RT3D for modeling degrading plumes of PCE, and related breakdown products, in three-dimensional groundwater flow systems (Clement et al, 1999).

MODFLOW was also the groundwater flow modeling software used for the initial groundwater model developed in support the initial draft of the Biodegradable Site Remedial Investigation in 2004. This earlier groundwater model simulated the transport of PCE and TCE using the Mass Transport 3-Dimension (MT3D). MT3D simulates the spread and transport of a single solved contaminant within a groundwater flow system. RT3D is a generalized, multi-species version of MT3D that runs the numerical solvers for advection and dispersion but has additional software functions to simulate the simultaneous

transport of multiple disssolved contaminants within the same groundwater system.

The earlier RI groundwater model simulated groundwater flow through a groundwater model study area that included the Beltsville Industrial Park, Indian Creek, the WMATA Maintenance Yard, and the USDA Carver Center. The groundwater model consisted of three aquifer layers with uniform hydraulic properties. The MT3D fate and transport model simulated PCE and TCE movement by assigning the following values to the following simulated contaminant sources:

- Ballard Property PCE Source Concentration of 150,000 µg/L (solubility limit of PCE in water)
- Ballard Property TCE Source Concentration of 200 µg/L (maximum observed value from on-site monitoring well at that time)
- Biodegradable Site TCE Source Concentration of 100 µg/L (maximum observed value from on-site monitoring wells at that time)

Several simulations were run through the year 2098, assuming various source removal efforts that were projected, in 2004, to be completed in the future. These simulations predicted that concentrations of PCE would reach 1,000 µg/L in the shallow wetland waters around the Biodegradable Site by 2098. These model results are considered unrealistic because MT3D cannot simulate the breakdown of PCE into daughter products. In addition, since the development of this groundwater model in 2004, a much larger volume of site related data has become available that includes:

- Detailed boring logs from wells advanced to depths of up to 140 feet
- Groundwater elevation data from contemporaneous well gauging events that included wells associated with both the Ballard Site and the Biodegradable Site Remedial Investigation
- The installation of several additional monitoring wells to the site in 2008 and 2010 that provide additional data points for evaluation of the extent of the PCE and TCE contaminant plumes.
- Groundwater monitoring data from the vicinity of the Ballard Site that was collected during contemporaneous groundwater sampling events.

The availability of this additional data, combined with the use of RT3D (instead of MT3D) to simulate the spread of the chlorinated solvent plume, has lead to a more accurate set of computer models. Additional geologic and hydrogeologic data lead to the development of a more accurate groundwater flow model. RT3D allowed for the simulation of PCE biodegradation to match spatial patterns of groundwater contamination observed within the site.

1.5 Report Organization

This report presents the development and calibration of a groundwater flow model and an associated contaminant fate and transport model that was used to simulate the spread of a VOC plume under the Biodegradable Site within the Beltsville Agricultural Research Service (BARC).

Section 1 summarizes the site history, study objectives, and computer models used to simulate groundwater movement. Section 2 summarizes site hydrology, geology, topography and surface water features used to develop the conceptual groundwater model. Section 3 summarizes the development of the groundwater flow model and the contaminant fate and transport model. Section 4 summarizes groundwater flow simulations and model calibrations. Section 5 summarizes reactive transport simulations and the data used to estimate time-specific source concentrations. Section 6 presents a discussion on the findings and conclusions.

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2. GROUNDWATER MODEL STUDY AREA

This section presents and describes relevant physical features associated with the study area, and are derived from the various investigations, well installation programs (e.g., boring logs, groundwater elevations), and the draft RI prepared in 2004. These features are important aspects that will be used to develop the Conceptual Site Model in Section 3, and as inputs to the MODFLOW model.

2.1 Site Description

The Biodegradable Site (Site) is located in Beltsville, MD, approximately 11 miles northeast of downtown Washington, DC. The Site lies south of Sunnyside Avenue and west of Edmonston Road, just outside the Capitol Beltway. The Site is located within, and adjacent to non-tidal wetlands associated with Indian Creek. The former landfilling operations at the Site filled in a portion of the wetlands. As mentioned in Section 1, the property was transferred to WMATA to build a rail maintenance facility; however, ARS has retained full responsibility for addressing ongoing environmental concerns. The portion of the Site that has not been built upon is flat, open, and grass covered. The Beltsville Industrial Park is located northwest of the site, along Sunnyside Avenue. Based on aerial photography, this industrial park has been in existence for at least 50 years. The industrial park contains numerous commercial, industrial, and manufacturing businesses, including the Ballard site. CSX railroad tracks run north-south long the western edge of the WMATA Rail Service Yard and the eastern edge of the Beltsville Industrial Park.

The study area measures 1,600 meters in the north-south direction and 1,100 meters in the east west direction, and encompasses: the Ballard Property, the Biodegradable Site, and Indian Creek. Groundwater flows south and east from the Ballard property. The Ballard property is located in the northwest corner of the study area as shown in Figure 1.3.

2.2 Topography

The Site is located in relatively flat-lying terrain. Elevations are higher to the west with overall elevations decreasing to the east and southeast as shown in Figure 2.1. The elevation northwest of the site, at the WMATA rail yard entrance along Sunnyside Avenue, is approximately 90 feet above mean sea level (MSL). Due east of the site at Indian Creek, the elevation is approximately 79 feet above MSL. This represents an average slope of less than 0.65 percent over a distance of approximately 1,700 feet.

The Beltsville Industrial Park has a maximum elevation of approximately 135 feet above MSL in the vicinity directly north of the Ballard property. From the Ballard property, ground slopes southward to Sunnyside Avenue and eastward toward the CSX rail road tracks. The Indian Creek stream valley is a wide and relatively flat channel that extends from the CSX railroad tracks to the west to Edmonston Road to the east. The stream valley slopes to the south.

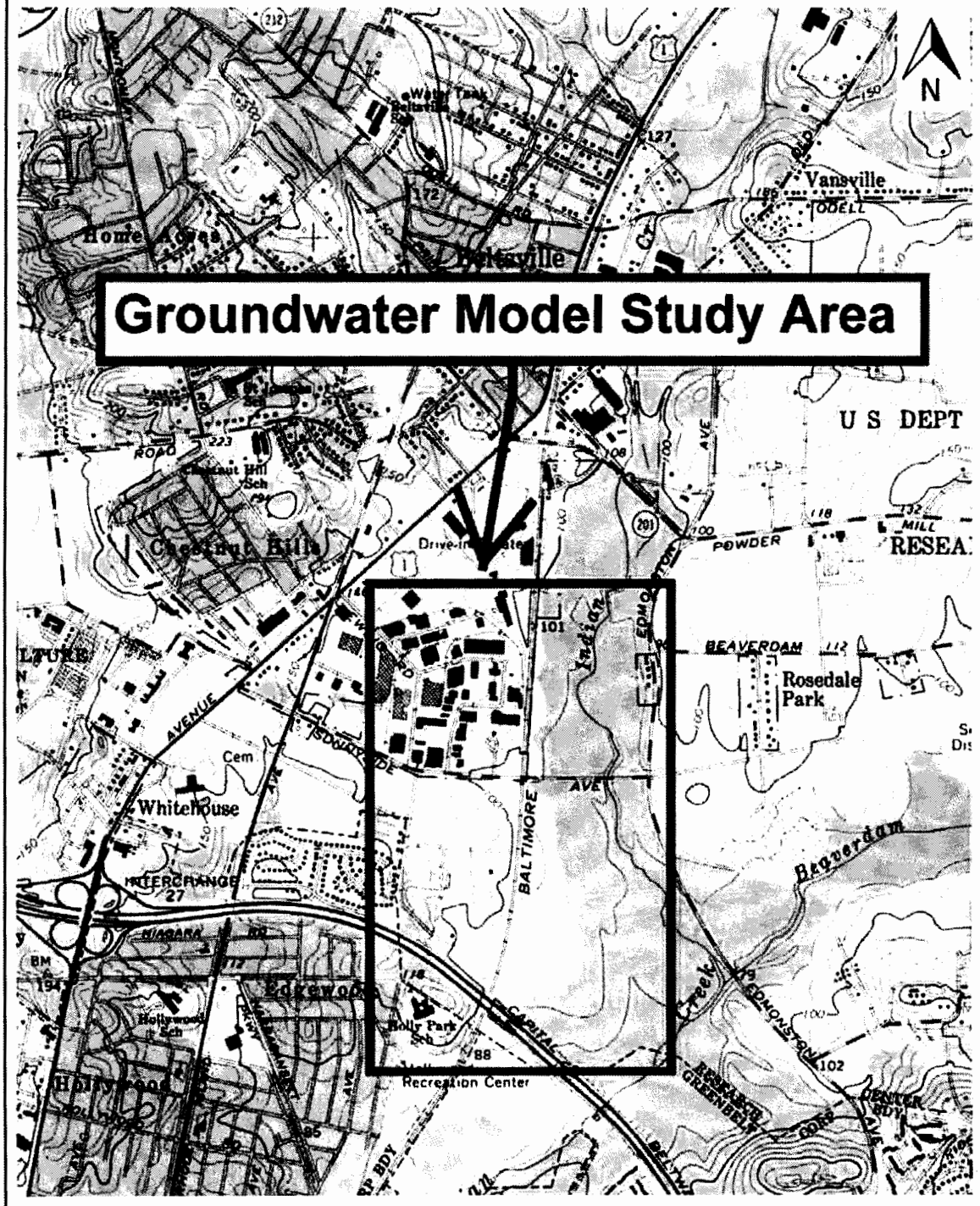


Figure 2.1
Topographic Features in Beltsville, MD
Source: USGS 7.5-Minute Topographic Map, Beltsville Quadrangle, 2011

2.3 Surface Water Features

Indian Creek is a perennial stream that flows north to south in the study area. Beaverdam Creek, which enters the groundwater model study area at the south-eastern quadrant flows to the west into Indian Creek. Average annual flow for Beaverdam Creek is 2.4 cubic feet per second (ft^3/s), based on a gauging station located just upstream of the confluence with Indian Creek (Apex Environmental, 1994). No stream gauging information is available for Indian Creek; however, based on size comparison, flow is likely comparable to Beaverdam Creek (i.e., 1.1 to 2.2 cf/s).

Based on field observations and measurements conducted during surface water sampling activities, both Indian Creek and Beaverdam Creek are gaining streams. Indian Creek measures approximately 2-3 meters across and is approximately 1 meter deep in the center. Beaverdam Creek measures up to 6 meters across downstream of the junction with Indian Creek, and can be up to 2 meters deep in the center.

There are two storm water retention ponds on the WMATA Property, and one pond on the USDA Carver Center campus, all of which drain into Indian Creek to the east. Both features are fed primarily by stormwater collection systems within the GWCC to the west, the Beltsville Industrial Complex to the North, and from the WMATA rail yard.

2.4 Geology

Lithology data from the borehole logs of fifty-eight (58) monitoring wells located on USDA-ARS, WMATA, and Beltsville Industrial Complex property were used during the RI to define the area stratigraphy. Boring logs are provided in Appendix A. As determined from borehole logs and cross-sections, subsurface stratigraphy in the general vicinity of the Biodegradable Site consists of the following:

- Surficial wetland soils (the Johnston Soil Series)
- Surficial sandy soil with little gravel (the Galestown Soil Series)
- Surficial and underlying alluvium consisting of compact silt and clay (Arundel Clay)
- Surficial and underlying silty sand/sandy silt/clean sand with some gravel (the Patuxent Formation)
- Saprolite/weathered bedrock

Johnston Soil Series

The Johnston Soil Series is described in the Soil Conservation Service's Soil Survey of Prince Georges County as a silt loam and mixed alluvial soil, poorly drained, high in organic content, with a considerable amount of decaying vegetation, typically occurring on the flood plains of streams. It averages 2-3 feet in thickness along Indian and Beaverdam Creeks. It is largely saturated, with the water table normally

within 6 inches of the surface. It is believed that shallow groundwater discharges to these wetland soils in the vicinity of the Biodegradable Site (USDA, 1967).

Galestown Soil Series

The Galestown Soil Series is described in the Soil Conservation Service's Soil Survey of Prince Georges County as loamy, coarse and loose gravelly sand which typically occurs above stream drainage ways. It exists west and east of the Indian Creek stream valley. The soil series averages 3-4 feet in thickness and is largely unsaturated; the water table is normally found in the underlying alluvium and sandy aquifer. Rainfall infiltration generally percolates through the Galestown Soils and recharges the alluvium and sandy aquifer beneath (USDA, 1967).

Alluvium

Alluvial deposits of Indian Creek underlie the soils at the Biodegradable Site. The alluvial deposits are typically 15 to 20 feet thick. Alluvial deposits consist of interbedded sand and gravel with minor clay lenses. Alluvial deposits are believed to extend from Indian Creek westward underneath the site to approximately the location of the CSX railroad tracks (Apex, 1994).

Arundel Clay

The Arundel clay formation separates the Patuxent and Patapsco formations in the region and is a predominant geologic feature in BARCs East Farm. BARC 6 is located at the westernmost extent of the expression of the Arundel formation; therefore, the Arundel formation, if present in this area at all, is not expected to be a continuous confining layer. The Arundel formation was not consistently observed during monitoring well installation activities and does not act as a confining layer in the vicinity of BARC 6.

Patuxent Formation

The Patuxent Formation is described as consisting of interbedded and alternating silty sand and sandy silt layers with minor discontinuous clay lenses and gravel layers. The unit outcrops in the general vicinity of the site and dips to the southeast. Beneath the Biodegradable Site, bedrock dip is estimated to be approximately 1 degree, with an associated thickening of unconsolidated sediments above bedrock of approximately 90 feet per mile.

A map showing the approximate extent of these formations within the groundwater study area is provided as Figure 2.2

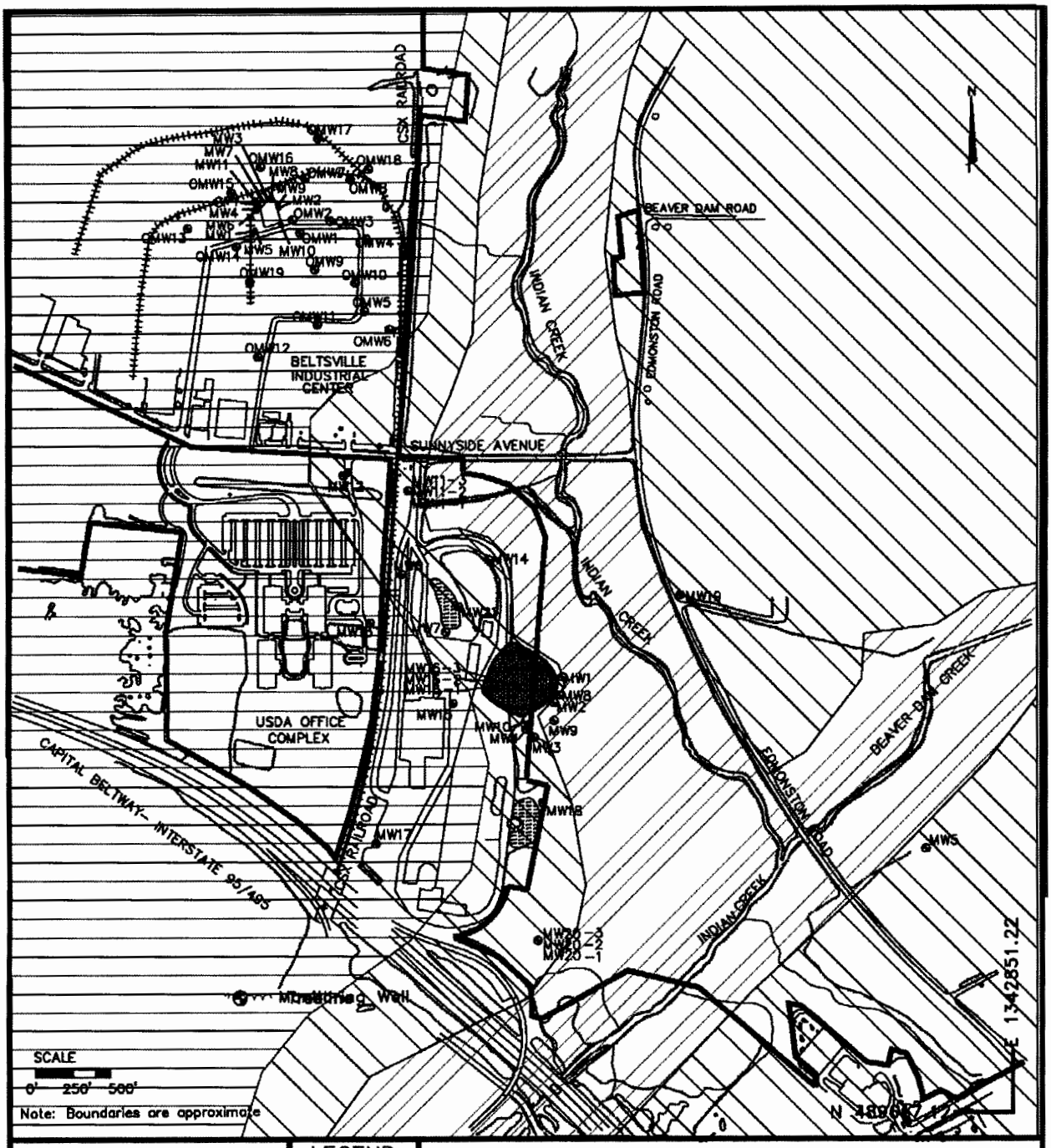


Figure: 2.2

Surface Geology in the Vicinity of the Biodegradable Site
Source: Mack, 1966
Modified by BMT, 2015

BMT Designers & Planners

LEGEND

- Building
- BARC6
- BARC Boundary
- Road
- Creek
- Railroad
- Patuxent Sands/Silts/Gravels
- Alluvium Sands & Galestown Soils and/or Arundel Formation
- Johnston Soils

Regional Geologic Formations

The site is located in the Atlantic Coastal Plain Physiographic Province, which is characterized by flat-topped stream divides and open valleys. The Biodegradable Site is underlain by formations ranging in age from Archaen (Early Precambrian) to recent, with large unconformities until the Lower Cretaceous Period (Mack, 1966). Unconsolidated sediments of the Lower Cretaceous comprise the majority of the near surface materials encountered at the site. These Lower Cretaceous sediments underlying BARC have been identified as the Potomac Group. From older to younger, the Potomac Group consists of the Patuxent, Arundel, and Patapsco Formations. Published geologic maps indicate that the Patuxent and Arundel Formations underlie BARC, whereas the Patapsco Formation may only be present in the eastern reaches of the BARC facility (Mack, 1966). A generalized cross section is included as Figure 2.3.

The Patuxent and Patapsco Formations are predominantly composed of sand and gravel materials while the intervening Arundel Formation is predominantly clay. All three formations dip to the southeast. The Arundel Clay is a more prominent geologic feature in BARCs East Farm. Moving to the east from the groundwater model study area, its presence becomes more prominent in the subsurface; however, in the vicinity of the Biodegradable Site the Arundel is observed to be intermittently encountered, and does not function as a continuous confining layer.

The Patuxent Formation is described as consisting of interbedded and alternating silty sand and sandy silt layers with minor discontinuous clay lenses and gravel layers. The Patuxent Formation outcrops in the general vicinity of the groundwater study area; however, outcrops of the Patuxent Formation have not been observed in the area due to the presence of a thin layer of alluvium associated with Indian Creek. . The total thickness of the Patuxent aquifer system ranges from 125 ft near the outcrop area to approximately 525 feet on the Eastern Shore of Maryland (MGS, 2011). A map showing the regional outcrops of the Patuxent Formation is presented as Figure 2.4. The groundwater model study area is located near the border of the Patuxent Formation outcrop.

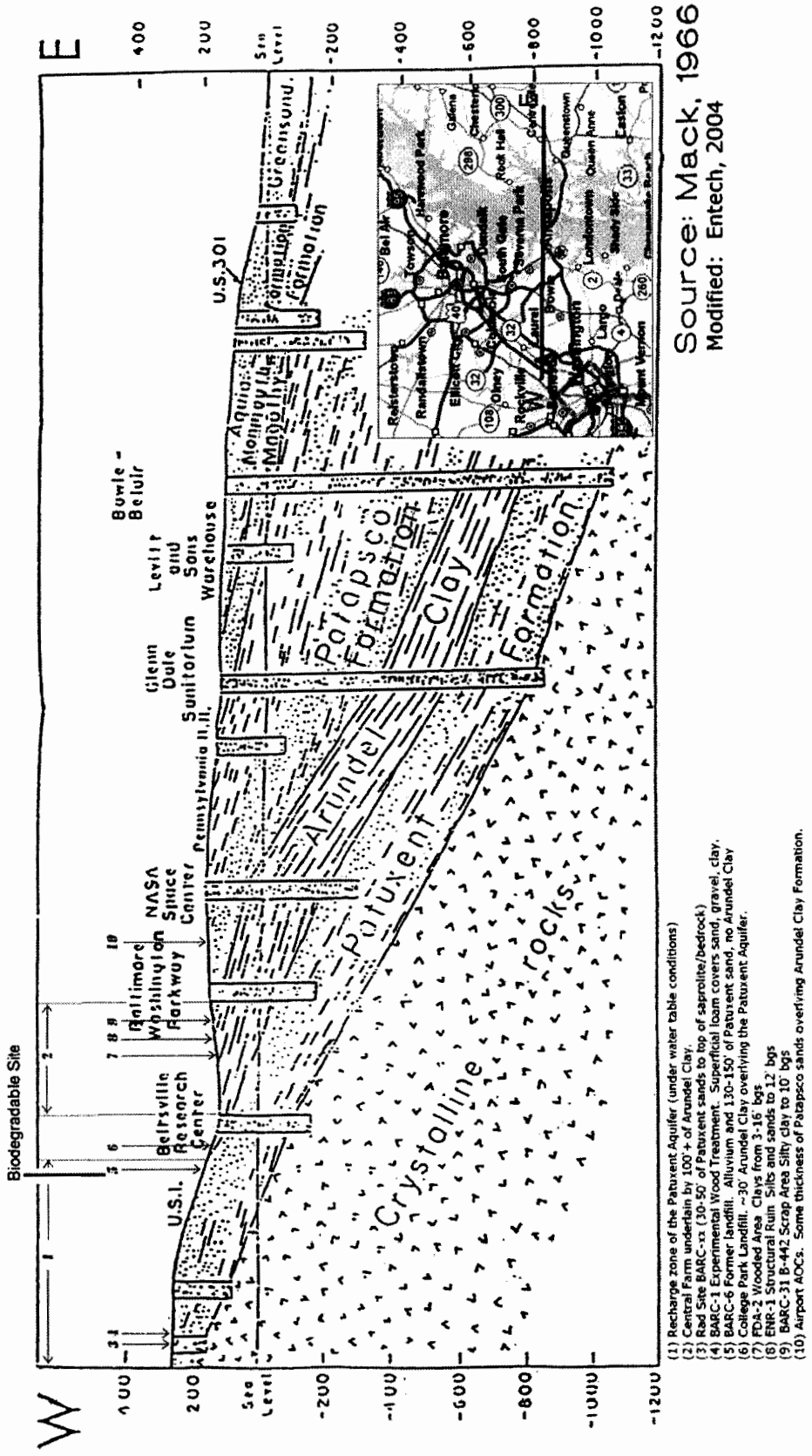
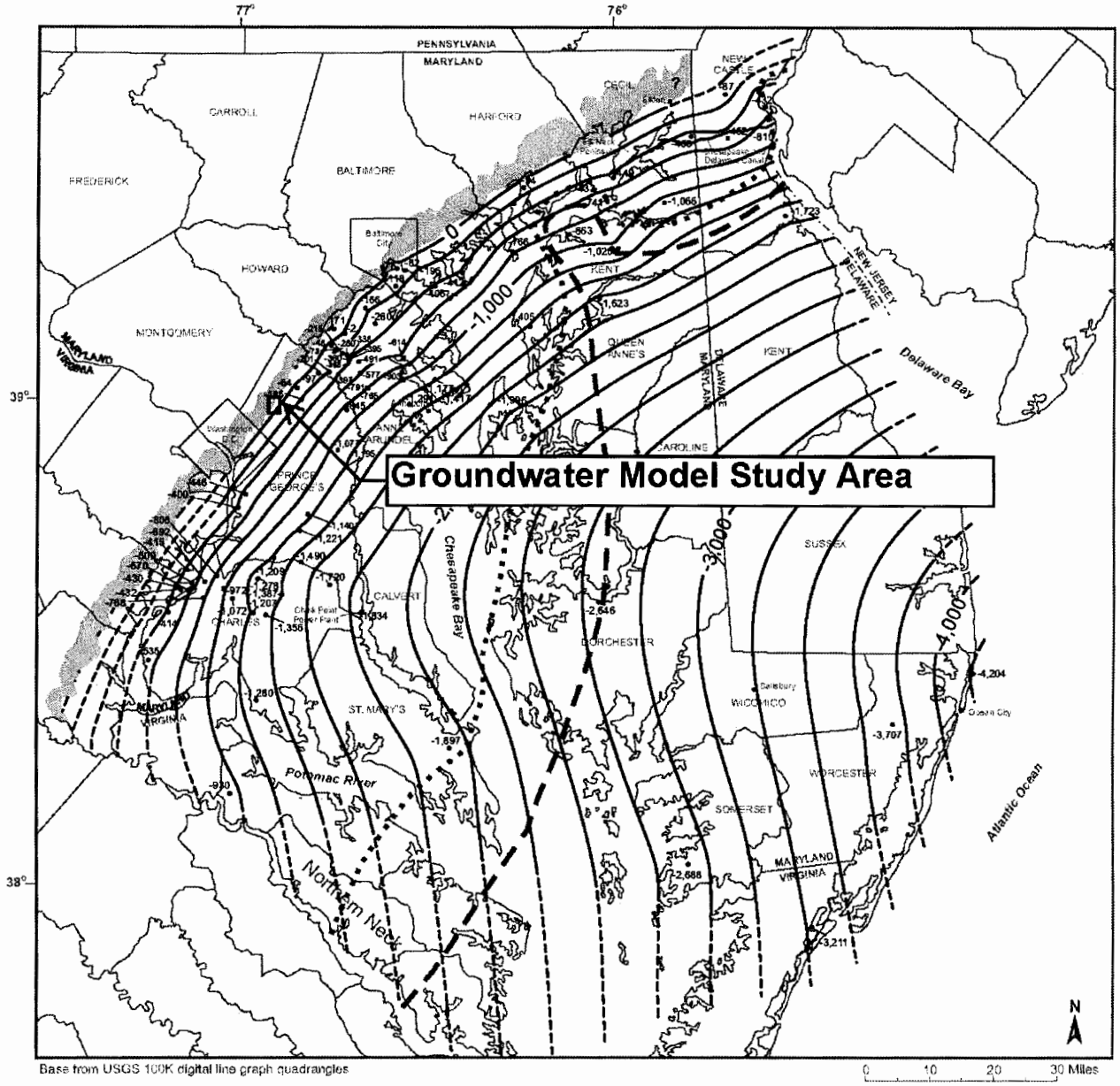


Figure 2.3. General Geologic Cross Section of Groundwater Study Area



EXPLANATION

-2,000 — Altitude of the top of the Patuxent aquifer system. Dashed where inferred. Contour interval is 200 feet. Datum is sea level.

-930 — Borehole--Number is altitude of the top of the Patuxent aquifer system, in feet related to sea level.

Approximate outcrop of the Patuxent aquifer system. Queried where uncertain.

Base of aquifer
Top of aquifer — 1,000 milligram per liter isochlor line (Meisler, 1989)

Figure 2.4 Patuxent Aquifer Outcrop Figure

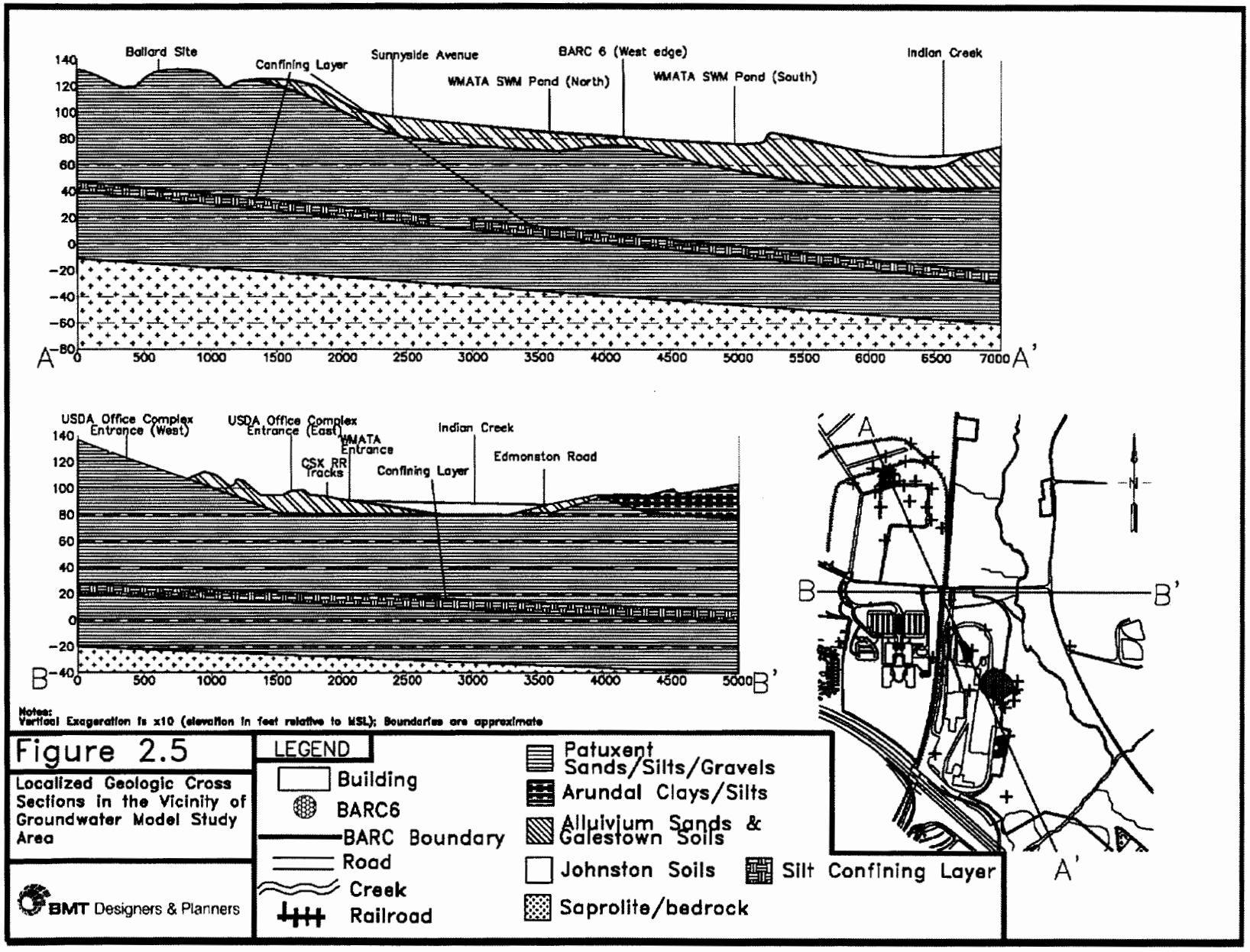
Source: Maryland Coastal Plain Aquifer Information System: Hydrogeologic Framework Open-File Report 12-02-20

Observed Subsurface Lithology

Consistent with the description of the Patuxent Formation, continuous boreholes advanced during the installation of several monitoring wells south of Sunnyside Avenue (BA6-MW11R, BA6-MW15R, and BA6-MW22 through BA6-MW25) revealed intermixed layers of silt, clay, and sand, with water bearing gravel layers containing little or no silt or clay. The water bearing sand and gravel layers are presumed to be preferential groundwater flow pathways within the groundwater study area. Consistent with published values, the observed thickness of the Patuxent Formation in the groundwater study area ranged from approximately 39 to 43 meters (129 to 140 feet). A competent clay layer was encountered at depths ranging from 129 to 139.5 feet. In several soil borings, a clay layer was not encountered and the borings were terminated in saprolite at depths of 120 feet or greater. Soil boring logs are included as Appendix A.

Subsurface lithology from north of Sunnyside Avenue was derived from boring logs produced during the installation of off-site monitoring wells (OMWs) within the Beltsville Industrial Park. Similar to soil boring advanced south of Sunnyside Avenue, reported lithology consisted of alternating layers of silt, sand and gravel; however, the relative thickness of each layer could not be determined due limitations associated with split spoon sample collection methodology. Monitoring wells OMW-21 through OMW-28 were terminated at depths ranging from 65 to 70 feet, corresponding to observed low permeability material described as gray clay. Soil borings were not advanced through this low permeability layer and the thickness was not determined. Soil boring logs for OMWs are included in Appendix B. Continuous boring logs from the installation of monitoring wells BA6-MW22, BA6-MW23, and BA6-MW25 encountered a similar layers of low permeability material described as light brown and gray compacted silts and silty clays at depths ranging from 52 to 84 feet with a thickness ranging from 3.5 at BA6-MW25 to up to 15 feet at BA6-MW23. These layers of material served as a confining layer to separate deep and shallower aquifer units in 5 out of 6 of the nested wells. Generally, this confining layer was encountered at greater relative depths towards the western extents of the groundwater model study area and the thickness of this layer increased towards the eastern extents. This confining layer was comprised of different materials in different wells, suggesting that this thin low permeability layer is not continuous throughout the groundwater study area.

Cross sections derived from monitoring well data within the groundwater model study area is presented in Figure 2.5.


Ballard Site
Confining Layer
Sunnyside Avenue
BARC 6 (West edge)
WMATA SWM Pond (North)
WMATA SWM Pond (South)
Indian Creek
A
A'
USDA Office Complex Entrance (West)
USDA Office Complex Entrance (East)
WMATA Entrance
CSX RR Tracks
Indian Creek
Confining Layer
Edmonston Road
B
B'
Notes:
Vertical Exageration is x10 (elevation in feet relative to MSL); Boundaries are approximate
Figure 2.5
Localized Geologic Cross Sections in the Vicinity of Groundwater Model Study Area
BMT Designers & Planners
LEGEND
Building
BARC6
BARC Boundary
Road
Creek
Railroad
Patuxent Sands/Silts/Gravels
Arundal Clays/Silts
Alluivium Sands & Galestown Soils
Johnston Soils
Silt Confining Layer
Saprolite/bedrock

2.5 Hydrology

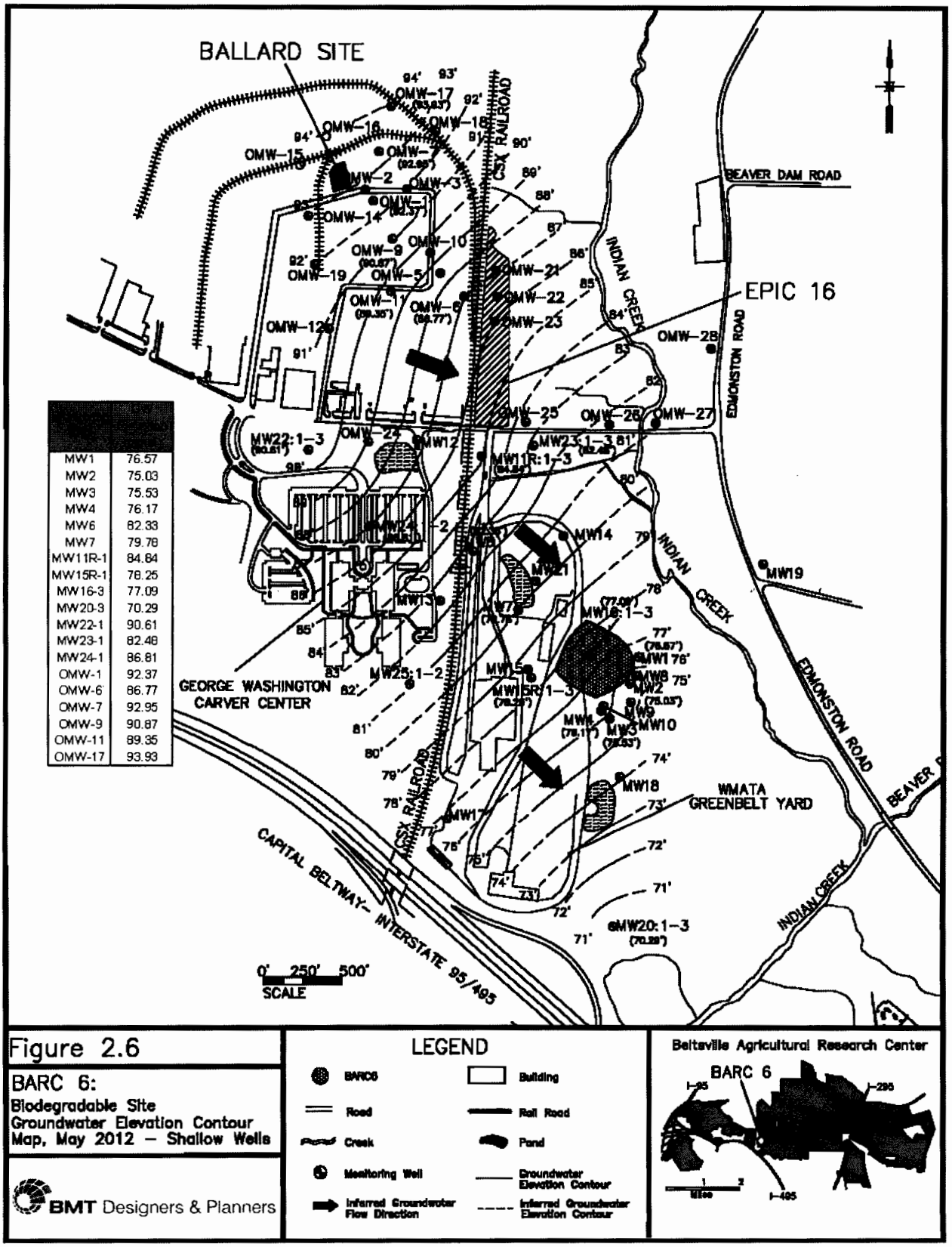
Regionally, groundwater flows towards Indian Creek and Beaverdam Creek. Both surface water features are gaining streams. Surface water runoff from the Beltsville Industrial Park, the GWCC and WMATA Greenbelt Yard is conveyed via stormwater collection systems to retention ponds within BARC and WMATA property before discharging to Indian Creek.

Within the groundwater model study area are two discrete hydrologic units that are separated by a single discontinuous confining layer or a series of confining layers. The discontinuous confining layer appears to increase in thickness in the eastern extent of the study area. Consistent with that observation, artesian conditions have been consistently observed in the deepest channels of monitoring wells BA6-MW20 and BA6-MW23 (Figure 1.3). Additionally, higher groundwater elevations (potentiometric surface) have been consistently observed in all wells screened at depths below the discontinuous confining layer within the groundwater model study area. These observations are consistent with a semi-confined hydrologic unit. The shallow aquifer unit that extends from the ground surface to the discontinuous confining layer and the deeper aquifer unit extends from this discontinuous confining layer to the underlying clay or saprolite. The presence of PCE and degradation products in groundwater within the deep aquifer unit indicates that one or more discontinuities exist within this layer and/or that it has greater permeability at certain locations.

Shallow Aquifer Unit

Within the groundwater model study area, groundwater flows from the Ballard property east-southeast, towards Indian Creek at a gradient of approximately 0.011 feet per foot (ft/ft). Groundwater south of Sunnyside Avenue flows to the southeast, toward the Biodegradable site at a gradient of approximately 0.0056 ft/ft. Groundwater elevations measured within the northwest corner of the groundwater model study area are typically 25 to 30 feet higher than those measured within its' southern extents. A groundwater elevation contour map for the shallow aquifer unit is presented as Figure 2.6.

Hydraulic conductivity and groundwater travel time is highly variable within the shallow aquifer unit. During the removal action at the Biodegradable Site, hydraulic conductivity was calculated within the shallow soils around the Biodegradable Site footprint by measuring the changes in groundwater elevations caused by dewatering. A value of 2.8 feet per day was calculated for the shallow soils in the vicinity of the Biodegradable SIte (KCI, 1994).


BALLARD SITE
EPIC 16
BEAVER DAM ROAD
EDMONSTON ROAD
INDIAN CREEK
GEORGE WASHINGTON CARVER CENTER
WMATA GREENBELT YARD
CAPITAL BELTWAY- INTERSTATE 95/495
B&O RAILROAD
MW1 76.57
MW2 75.03
MW3 75.53
MW4 76.17
MW6 82.33
MW7 79.78
MW11R-1 84.84
MW15R-1 78.25
MW16-3 77.09
MW20-3 70.29
MW22-1 90.61
MW23-1 82.48
MW24-1 86.81
OMW-1 92.37
OMW-6 86.77
OMW-7 92.95
OMW-9 90.87
OMW-11 89.35
OMW-17 93.93
0' 250' 500'
SCALE
Figure 2.6
BARC 6:
Biodegradable Site
Groundwater Elevation Contour
Map, May 2012 – Shallow Wells
BMT Designers & Planners
LEGEND
BARC6
Building
Road
Rail Road
Creek
Pond
Monitoring Well
Groundwater Elevation Contour
Inferred Groundwater Flow Direction
Inferred Groundwater Elevation Contour
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495
Miles

Slug tests were performed on seven (7) monitoring wells around the Biodegradable Site during the RI in 2003. Hydraulic conductivity was calculated using the Bouwer-Rice method and ranged from 2.7 to 23 feet per day and estimated groundwater flow velocities ranged from 20 to 120 feet per year (BMT Entech, 2004).

Slug tests were performed on ten (10) additional wells along Sunnyside Avenue in 2010 in support of the groundwater modeling effort. Nine (9) of these wells consisted of groupings of 3-nested well channels that were screened at various depths. Measured hydraulic conductivities are consistent with values derived from earlier investigations. Groundwater recovery during slug tests in several wells occurred too quickly to provide an adequate data set for the calculation of hydraulic conductivity, presumably due to very high hydraulic conductivity. The results of the 2010 slug tests are summarized in Table 2.1.

Table 2.1. 2010 Slug Test Data Summary

Hydraulic Conductivities (K) Estimated from Slug Tests performed on 2010				
Well	**Rising/Falling**	**K (cm/s)**	**K (ft/d)**	**Average (ft/d)**
MW12	Rising	3.25E-04	0.92	0.85
MW12	Falling	2.77E-04	0.79	
MW11R-1	Rising	9.80E-04	2.78	3.08
MW11R-1	Falling	1.19E-03	3.37	
MW11R-2	Rising	1.77E-03	5.02	4.54
MW11R-2	Falling	1.43E-03	4.05	
MW11R-3	Rising	Unmeasurable*		
MW11R-3	Falling	Unmeasurable*		
MW22-1	Rising	3.09E-05	0.09	0.10
MW22-1	Falling	3.62E-05	0.10	
MW22-2	Rising	Unmeasurable*		
MW22-2	Falling	Unmeasurable*		
MW22-3	Rising	Unmeasurable*		
MW22-3	Falling	Unmeasurable*		
MW23-1	Rising	8.77E-03	24.86	22.80
MW23-1	Falling	7.32E-03	20.75	
MW23-2	Rising	Unmeasurable*		
MW23-2	Falling	Unmeasurable*		
MW23-3	Rising	Unmeasurable*		
MW23-3	Falling	Unmeasurable*		

*Rising and falling head recovery too rapid to derive values for hydraulic conductivity

Based on existing aquifer testing data, the bulk hydraulic conductivity of the shallow aquifer unit ranges from 0.10 to 23 feet per day. Monitoring wells that were included in the 2010 slug testing program have screened intervals of 10 to 70 feet, many of which are screened through alternating layers of gravel, sand, silt and clay. Individual layers may have hydraulic conductivities much greater than the bulk hydraulic conductivity values calculated during aquifer testing. Published hydraulic conductivity values for clean sand and gravel formations can range from 0.1 to 1 cm/s (approximately 280 to 2,800 feet per day) (Freeze & Cherry, 1979). Gravel formations can have hydraulic conductivities that are even higher. Sand and gravel layers were encountered within the shallow aquifer unit within boreholes advanced within the groundwater model study area.

Deep Aquifer Unit

A total of eight (8) well channels are screened within the deep aquifer unit (MW11R-3, MW15R-3, MW16-1, MW20-1 MW22-3, MW23-3, MW24-2, and MW25-2). All of these wells are located south of Sunnyside Avenue. As a result, the properties of the deep aquifer unit within the northern half of the groundwater model study area have not been confirmed with field measurements. Based on groundwater elevation measurements from these monitoring wells, groundwater within the deep aquifer unit flows south-south east from the GWCC toward the southern portion of the WMATA Greenbelt Yard at a gradient of approximately 0.0051 ft/ft. A groundwater elevation contour map for the deep aquifer unit is included as Figure 2.7.

Slug test were conducted on a total of three (3) monitoring wells (MW11R-3, MW22-3, and MW23-3) screened within the deep aquifer unit. Groundwater recovery during these slug tests occurred too quickly to provide an adequate data set for the calculation of hydraulic conductivity, presumably caused by high hydraulic conductivity within the aquifer unit (Table 2.1). Based on available boring logs, the deep aquifer unit is comprised largely of sand and gravel with some silt. Published hydraulic conductivity values for sand and gravel range from 0.1 to 1 cm/s (approximately 280 to 2,800 feet per day) and are consistent with the quick recovery observed during slug tests (Freeze & Cherry, 1979).

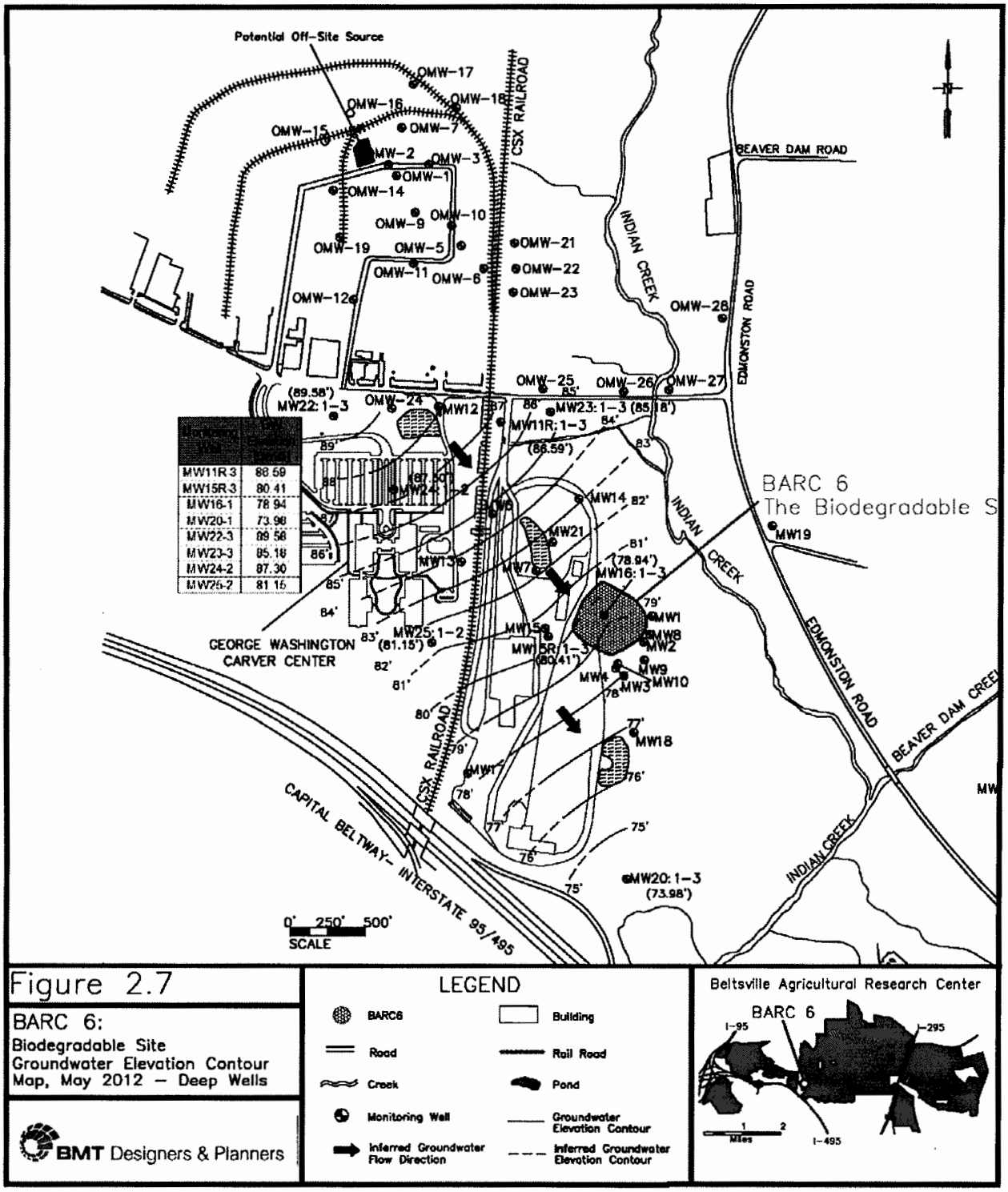


Figure 2.7

BARC 6:
Biodegradable Site
Groundwater Elevation Contour
Map, May 2012 – Deep Wells

BMT Designers & Planners

LEGEND

- BARC6
- Building
- Road
- Rail Road
- Creek
- Pond
- Monitoring Well
- Groundwater Elevation Contour
- Inferred Groundwater Flow Direction
- Inferred Groundwater Elevation Contour

Beltsville Agricultural Research Center

2.6 History and Extent of Groundwater Contamination

The nature and extent of groundwater contamination at the Biodegradable Site and the surrounding area is described in detail in the draft Remedial Investigation Report (BMT, 2004) and in the annual sampling reports that are summarized in Appendix C. The history of groundwater monitoring activities at the Biodegradable site and surrounding area and the current extent of CAH contamination in groundwater within the model study area, the subject of the groundwater fate and transport model, are discussed in this subsection.

As part of the PA/SI and subsequent Phase 1 and Phase 2 Environmental Investigations, several monitoring wells were installed in the vicinity of the Biodegradable Site (BA6-MW1 through BA6-MW10) (Figure 1.3). The CAHs TCE and 1,1-DCE were detected in monitoring well BA6-MW10 at a maximum concentration of 100 µg/L and 45 µg/L, respectively. PCE was either not detected or was detected at low concentrations during these investigations; however, PCE was detected in surface water samples collected from Indian Creek during the same investigations at concentrations ranging from 6 to 25 µg/L. The highest concentrations of PCE in surface water were detected from surface water sample locations upgradient of the Biodegradable Site (Apex, Inc., 1994).

A Non-Time Critical Removal Action (NTCRA) at the Biodegradable Site was completed in 1993 that included the removal and off-site disposal of approximately 70,000 tons of soil, waste, and debris. During the removal action, PCE was not detected in any of the soil samples collected within the area excavated, and TCE was detected only once, at low concentrations. To facilitate the removal action, a dewatering system was operated to lower the water table beneath the Biodegradable Site. Groundwater removed from the excavation was treated prior to discharge in accordance with a National Pollutant Discharge Elimination System (NPDES) permit. CAHs were consistently detected in treatment system influent samples at concentrations consistent with CAH concentrations detected in surrounding monitoring wells ranging from 5.4 to 43 µg/L for TCE, and 1.1 to 8.6 µg/L for 1,1-DCE respectively (BMT, 2014).

Ten (10) additional groundwater monitoring wells (BA6-MW11 through BA6-MW20) were installed upgradient and downgradient of the Biodegradable Site in 1997, and a regular groundwater monitoring program was implemented (Figure 1.3). PCE, TCE and 1,1-DCE are the primary CAHs detected in the vicinity of the Biodegradable Site since the implementation of regular groundwater sampling program in 1998. The highest concentrations PCE and TCE are typically detected in monitoring wells BA6-MW12 and BA6-MW13, located upgradient of the Biodegradable Site. TCE and 1-1,-DCE were detected at concentrations of 44.5 and 15 µg/L, respectively, in monitoring well BA6-MW20, which is the most downgradient monitoring well, located approximately 1 mile south-southeast of the Ballard Site and approximately 1,500 feet south of the Biodegradable Site. CAH concentrations detected in

Biodegradable Site wells have either remained relatively constant or have decreased during the groundwater sampling program from 1998 to 2010.

Three (3) of the Biodegradable Site monitoring wells (BA6-MW11-1, BA6-MW16-1 and BA6-MW20-1) were screened within the deep aquifer unit and represent the first groundwater quality data from the deep aquifer unit (BMT Entech, 2004). CAHs were not historically detected in monitoring well BA6-MW11-1. BA6-MW11 was destroyed in 2010 due to construction activities. BA6-MW11R was installed in the same location in 2011 to replace it. Negligible concentrations of TCE and 1,1-DCE have historically been detected in monitoring well BA6-MW16-1 and BA6-MW20-1 (BMT, 2012).

Monitoring wells installed within the boundaries of the Ballard Site (Ballard Site wells) and throughout the Beltsville Industrial Park (off-site monitoring wells OMW-1 through OMW-20) have identified the presence of a large contaminant plume, primarily comprised of PCE, north of Sunnyside Avenue. Regular groundwater monitoring was conducted on these wells from 1999 to 2005. High concentrations of PCE were detected in Ballard Site wells. The maximum detected concentration of PCE was detected in Ballard Site Well MW-11 at 110,000 µg/L in 2003. An air sparging/soil vapor extraction system was also installed in 2002, in accordance with this plan. The soil vapor extraction (SVE) system began operation in November of 2002, and the air sparging system began operation in February of 2003 (Miller, 2003).

High concentrations of PCE were also detected in off-site monitoring wells OMW-1, OMW-2, OMW-9, OMW-10 and OMW-6 which are located downgradient of the Ballard Site, west of the nearby CSX railroad tracks. A peak concentration of 16,000 µg/L was detected in off-site monitoring well OMW-2 on March 26, 2004, which is located immediately downgradient of the Ballard Site. PCE degradation products TCE and 1,1-DCE have historically been detected at low concentrations or were not detected in these monitoring wells.

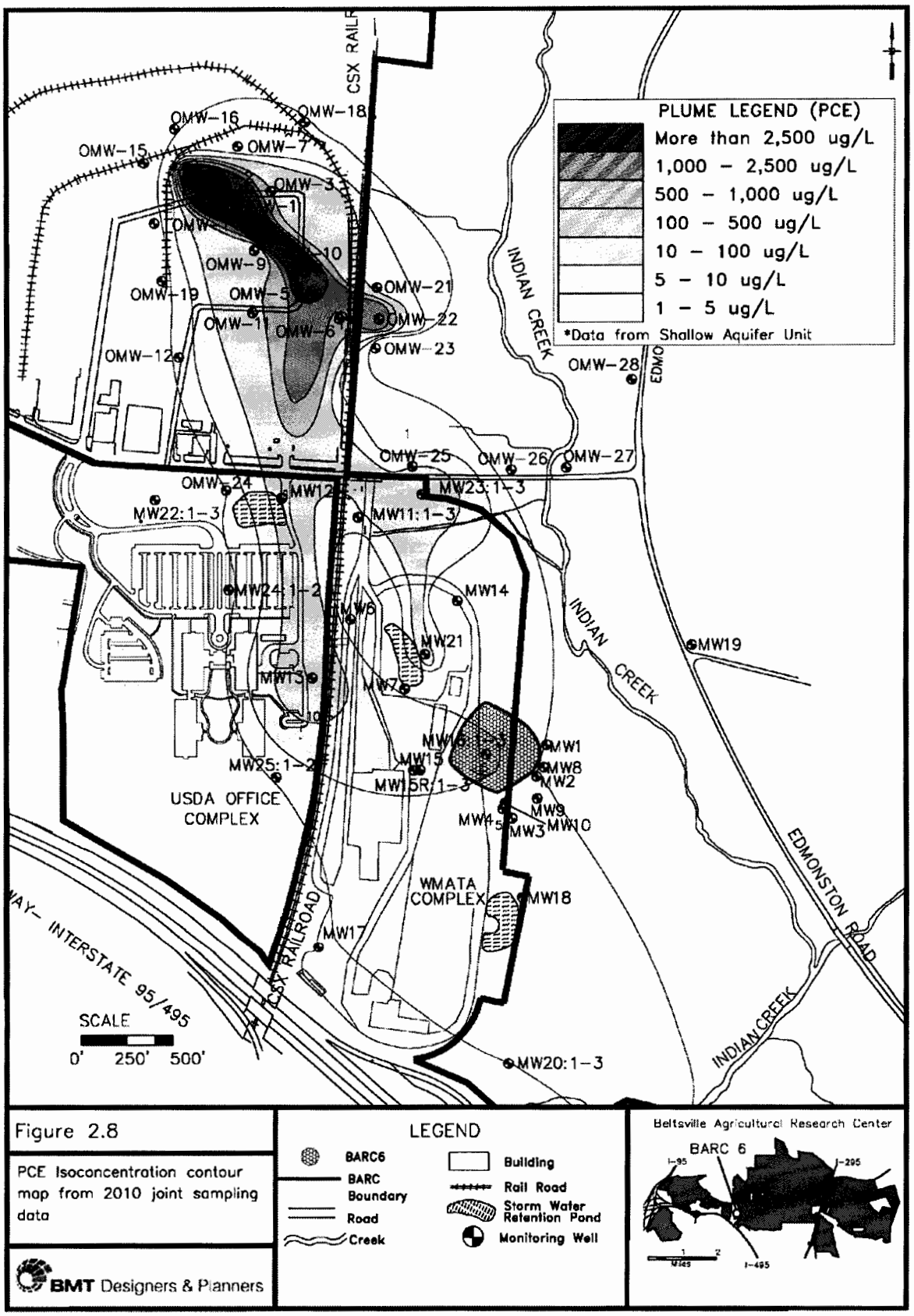
Additional off-site monitoring wells were installed downgradient of the Ballard site in 2008 (OMW-21 through OMW-28), including several wells close to Indian Creek adjacent to Sunnyside Avenue (OMW-26 and OMW-27) and Edmonston Road (OMW-28). PCE was detected at a maximum concentrations of 1,000 µg/L in OMW-22 in 2008. Off-site monitoring well OMW-22 is located downgradient of the Ballard Site, east of the CSX railroad tracks (due east of OMW-6). Additionally, the PCE degradation product TCE was detected in off-site monitoring well OMW-22 at maximum concentrations of 260 µg/L. CAHs were not detected in OMW-26, OMW-27 and OMW-28 which are located within the Indian Creek stream valley (AEC, 2008). Groundwater sampling results collected from groundwater monitoring around the Ballard Site from 1999 to 2008 are presented in Appendix B. Additional groundwater samples were collected from Ballard Site wells in 2010 and 2012 as part of contemporaneous joint-sampling activities.

In 2010 and 2011, additional monitoring wells (BA6-MW11R, BA6-MW15R, BA6-MW22, BA6-MW23, BA6-MW24 and BA6-MW25) were installed within BARC and WMATA property to further delineate the CAH plume. These monitoring wells each contain two or three well channels that are screened through distinct aquifer units, including the deep aquifer unit. PCE, TCE and 1,1-DCE were detected within well channels screened within the deep aquifer unit at MW15R-3, MW23-3, MW24-2 and MW25-2 (BMT, 2012). The greatest concentration of CAHs within the deep aquifer unit were detected within BA6-MW24 with PCE detected at a maximum concentration of 8.9 µg/L, TCE detected at a maximum concentration of 30 µg/L, and 1,1-DCE detected at a maximum concentration of 20 µg/L respectively.

The new monitoring wells that were installed in 2010 and 2011 provided additional information regarding the eastward and westward extents of the CAH plume upgradient of the Biodegradable Site and delineated the extents of the CAH plume within the deep aquifer unit. With the installation of these monitoring wells, there were enough well channels that were screened through the deep aquifer unit, within the groundwater model study area, to create accurate groundwater potentiometric maps for this aquifer unit.

Groundwater quality data collected from 1991 to 2014 indicates the presence of a large plume of PCE, TCE and isomers of DCE that extends from the Ballard Site to the southern border of the groundwater model study area and to the western extents of the Indian Creek stream valley. Collected groundwater monitoring data from the monitoring wells around the Ballard Site are provided in Appendix B. A copy of the BARC 6 Joint Monitoring Well sampling event from 2012 is provided in Appendix C.

A PCE isoconcentration contour map and a TCE isoconcentration contour map for the groundwater model study based on 2010 groundwater quality data are included as Figures 2.8 and 2.9, respectively. A Tag Map depicting 2010 groundwater quality analytical results for CAHs is included as Figure 2.10.


PLUME LEGEND (PCE)
More than 2,500 ug/L
1,000 – 2,500 ug/L
500 – 1,000 ug/L
100 – 500 ug/L
10 – 100 ug/L
5 – 10 ug/L
1 – 5 ug/L
*Data from Shallow Aquifer Unit
CSX RAILROAD
INDIAN CREEK
EDMONSTON ROAD
OMW-16
OMW-18
OMW-15
OMW-7
OMW-3
OMW-1
OMW-10
OMW-9
OMW-19
OMW-5
OMW-21
OMW-11
OMW-6
OMW-22
OMW-12
OMW-23
OMW-28
OMW-25
OMW-26
OMW-27
OMW-24
MW12:1-3
MW23:1-3
MW22:1-3
MW11:1-3
MW24:1-2
MW14
MW6
MW21
MW19
MW13
MW7
MW16
MW1
MW15
MW8
MW25:1-2
MW15R:1-3
MW2
USDA OFFICE COMPLEX
MW9
MW4
MW3
MW10
WMATA COMPLEX
MW18
MW17
INTERSTATE 95/495
SCALE
0' 250' 500'
MW20:1-3
Figure 2.8
PCE Isoconcentration contour map from 2010 joint sampling data
BMT Designers & Planners
LEGEND
BARC6
BARC Boundary
Road
Creek
Building
Rail Road
Storm Water Retention Pond
Monitoring Well
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495

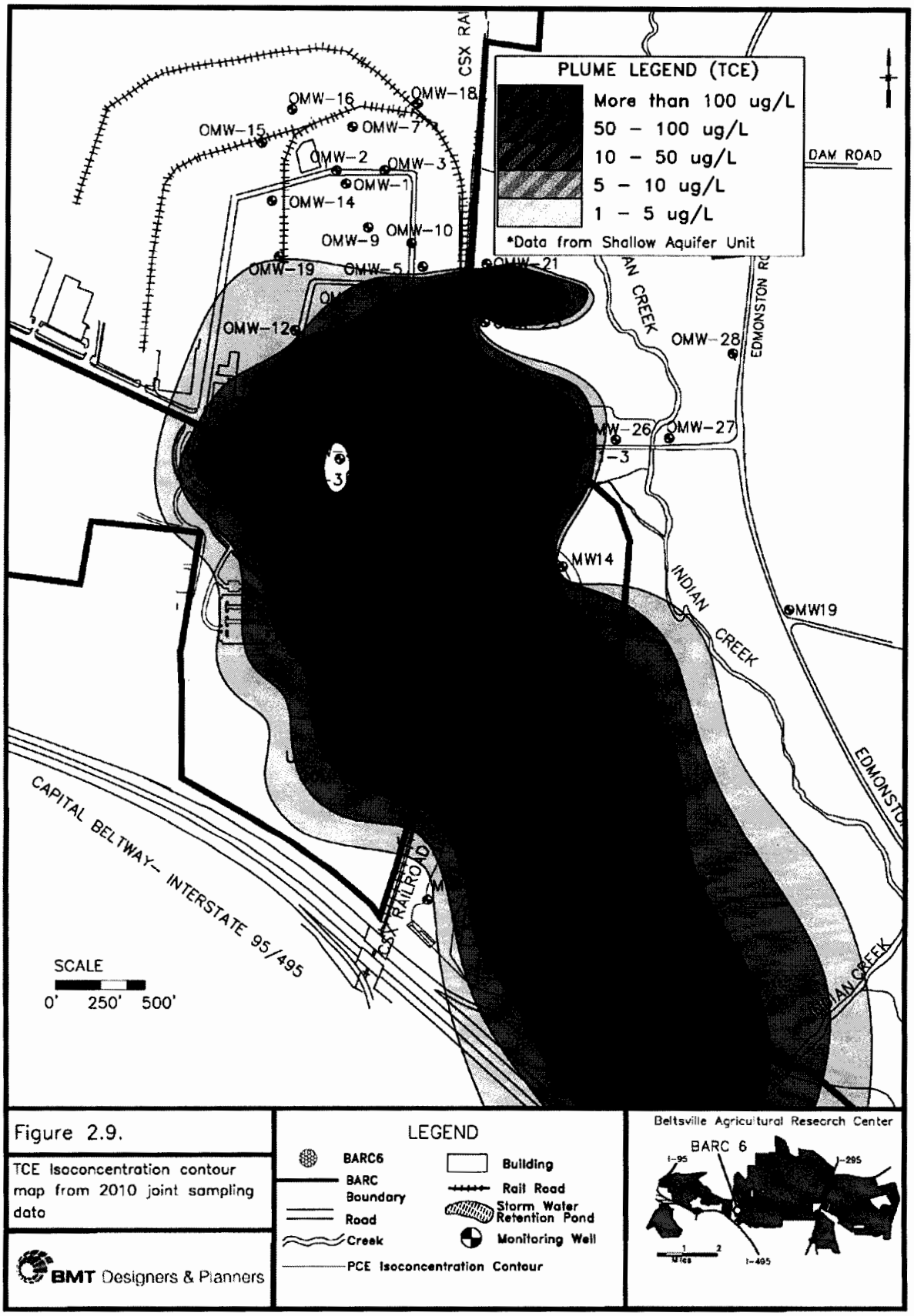


Figure 2.9.

TCE Isoconcentration contour map from 2010 joint sampling data

BMT Designers & Planners

3. CONCEPTUAL MODEL DEVELOPMENT

Based on the physical setting, published and observed geologic conditions for the site and surrounding area, and observed hydrologic conditions presented in Sections 1 and 2, a conceptual site model was constructed. This section identifies and describes conceptual site model inputs and describes the rationale for their use in the model. All input parameters for MODFLOW and RT3D are in metric units, which will be used from this point to define the conceptual site model. MODFLOW and RT3D model inputs are included as Appendix D.

3.1 Conceptual Groundwater Model

As discussed in Section 2, there are two discrete aquifer units underlying the site and groundwater study area. The shallow and a deep aquifer units are separated by a discontinuous confining layer present at depths ranging from approximately 22 to 25 meters (66 to 82 feet) below ground surface. The non-continuous nature of the confining layer is represented in the groundwater model by two discontinuities, or 'gaps', in the confining layer centered around BA6-MW24 and directly north of the WMATA yard along Sunnyside Avenue.

The shallow aquifer unit is further divided into a shallow zone and a deep zone to account for the different hydraulic conductivity values calculated during aquifer testing and to account for the presence of Indian Creek and Beaverdam Creek. Indian Creek and Beaverdam Creek are presumed to effect groundwater flow only within the shallow zone of the shallow aquifer unit and not the full saturated depth of the shallow aquifer unit.

Within MODFLOW, streams and rivers are simulated by using a River Package which has user defined inputs for: river width, river depth, hydraulic conductivity of the stream bed, thickness of sediments, and hydraulic potential at the river surface.

The sections below summarize the main features of the groundwater flow model that was constructed in MODFLOW to simulate groundwater conditions within the groundwater model study area. A description of the model grid, boundary conditions, initial hydraulic head, surface water features, time series, precipitation inputs and evapotranspiration losses are summarized below.

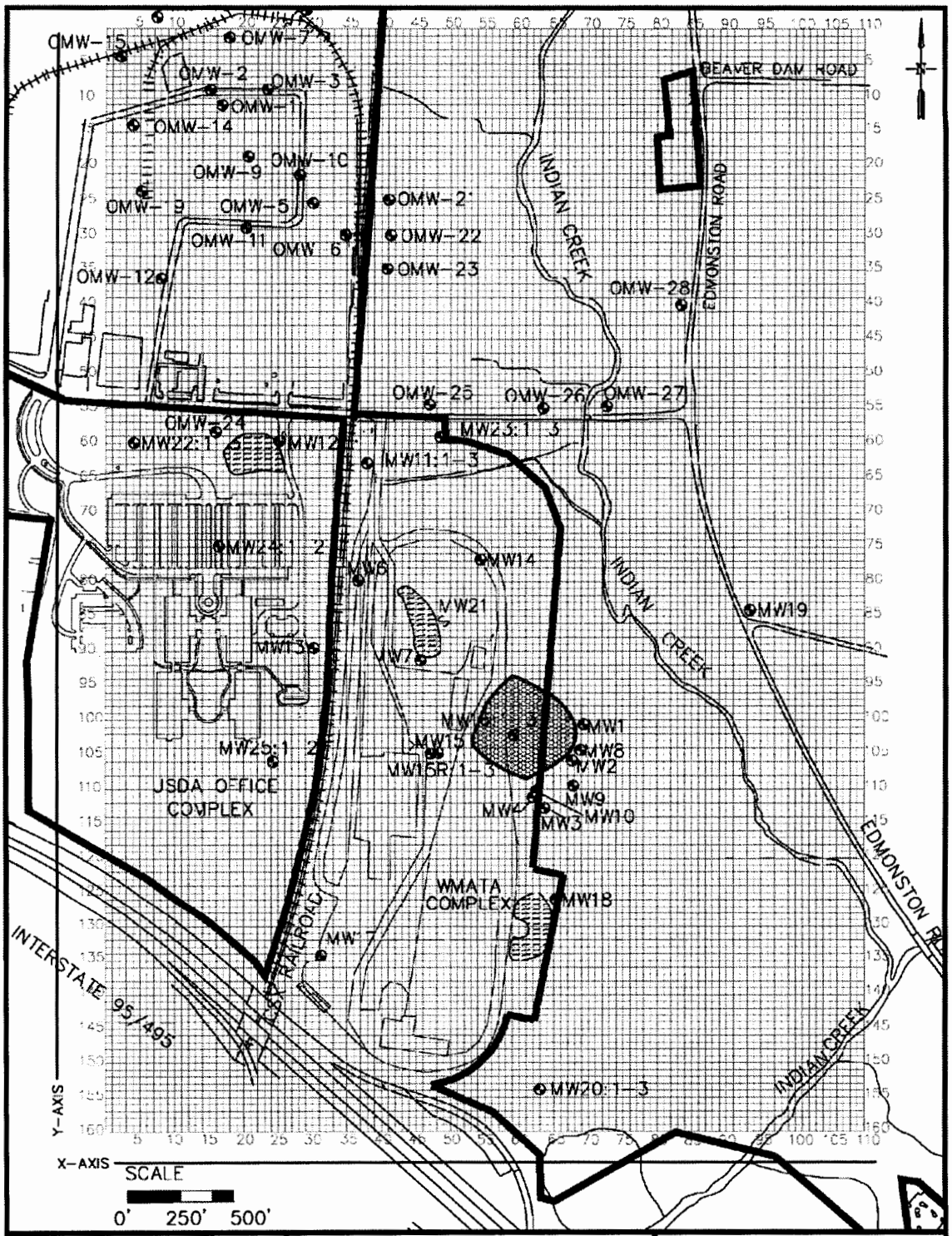


Figure 3.1.

Plan view of MODFLOW Finite-Difference Grid for Groundwater Model Study Area

BMT Designers & Planners

3.1.1 MODFLOW 3-Dimensional Grid

The groundwater flow model in MODFLOW is based on a finite difference grid with a uniform horizontal cell size of 10 meters x 10 meters (33 feet x 33 feet) and four vertical layers. The model grid is aligned with cardinal directions with the x-axis corresponding to the east-west axis, the y-axis corresponding to the north-south axis and the z-axis corresponding the vertical axis. A map showing the horizontal extent of the MODFLOW grid overlying the groundwater model study area is presented in Figure 3.1.

The shallow aquifer unit, the discontinuous confining layer and the deep aquifer unit are represented by four layers within the MODFLOW finite difference grid, which represent the z axis of the three-dimensional model. The shallow aquifer unit is represented by the top two layers and was divided to account for surface water influence in the upper layer and variation in measured hydraulic conductivity between the upper and lower sections of the aquifer unit. The discontinuous confining layer is represented by the third layer and the deep aquifer unit is represented by the fourth layer. A conceptual view of the vertical layers is included as Figure 3.2.

Each layer is assigned an anisotropy factor which is a user defined ratio of the hydraulic conductivity along the rows of the MODFLOW grid (y-axis) over hydraulic conductivity along the columns of the MODFLOW grid (x-axis). Thus an anisotropy factor 1.0 indicates a flow model where contaminants will spread in perfect alignment with the direction of groundwater flow while an anisotropy factor of 2.0 will indicate a flow model where contaminant flow will be biased in the direction of the y-axis of the model grid. A description of the vertical layers is presented below:

- **LAYER 1:** Layer 1 corresponds to the upper section of the shallow aquifer unit and has a thickness ranging from 8 to 10 meters (26 to 33 feet). Layer 1 has a highly variable hydraulic conductivity. An anisotropy factor of 1.2 was assigned to this layer based on the observed contaminant distribution in groundwater.

- **LAYER 2:** Layer 2 corresponds to the lower section of the shallow aquifer unit and has a thickness of 12 to 15 meters (39 to 49 feet). Similar to layer 1, the hydraulic conductivity of this layer is highly variable. The assigned anisotropy factor for this layer is 1.

- **LAYER 3:** Layer 3 represents the discontinuous confining layer that is observed at depths ranging from approximately 16 to 25 meters bgs (52 to 82 feet), with a thickness of approximately 1 meter. The discontinuous confining layer is a comprised of clays and compacted silt that separates the shallow and deep aquifer units within the groundwater model study area. Conceptually, this layer is considered an aquitard that prevents the vertical flow of groundwater from the shallow aquifer unit to the deep aquifer unit. MODFLOW defines a no-flow boundary by

assigning a hydraulic conductivity of 0 to this layer within the model and is consistent with this layers function as an aquitard.

Two discontinuities, or gaps, within this confining layer, were programmed into the model input for layer 3. One assigned gap is located north of Sunnyside Avenue, upgradient of BA6-MW23, to account for the presence of CAHs within BA6-MW23-3. The second assigned gap is located in the area of monitoring well BA6-MW24, due to the presence of relatively high concentrations of TCE and 1,1-DCE within the deep aquifer unit detected in this well. The assigned gaps were given a uniform shape and size to simplify the model calibration process. Figure 3.3 depicts the area and location of the assigned gaps in the discontinuous confining layer that separates the shallow and deep aquifer units. The soil properties of the gaps in the confining layer are considered to be uniform. The assigned anisotropy factor for this layer is 1.

- **LAYER 4:** Layer 4 corresponds to the deep aquifer unit and has a uniform thickness of 15 meters (49 feet). Layer 4 is bounded at the bottom by weathered bedrock which represents the lower boundary of the model and at the top by Layer 3. The assigned anisotropy factor for this layer is 1.

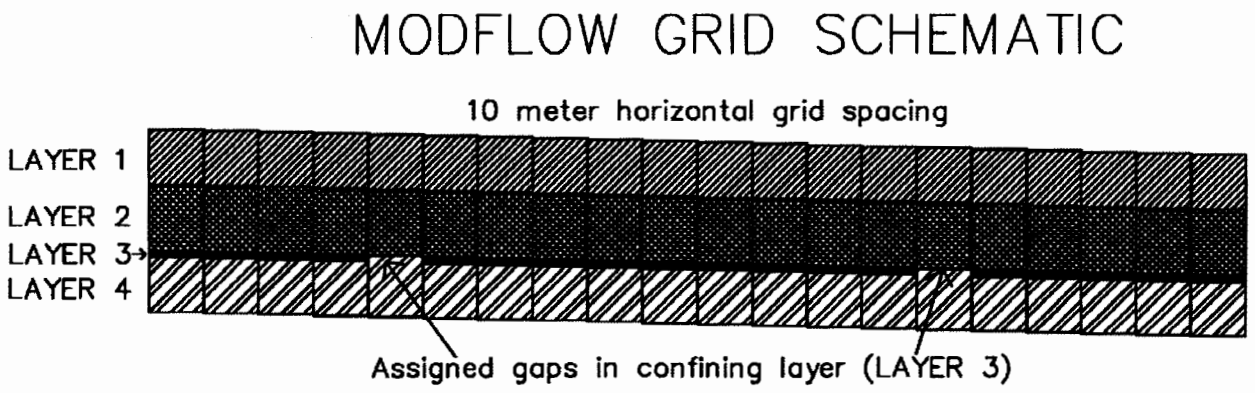
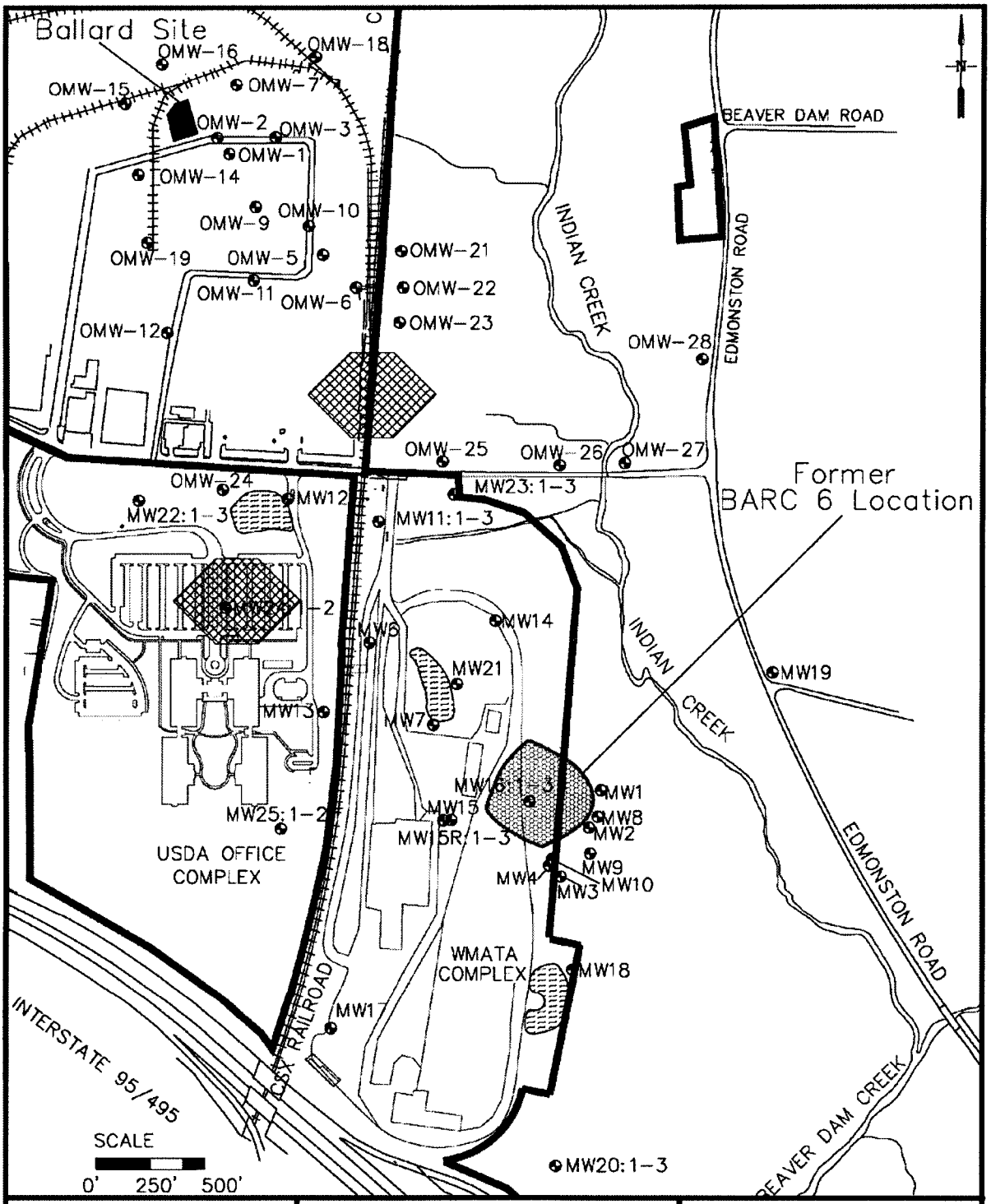


Figure 3.2: Model Grid Vertical Cross-Section Schematic (Figure not to Scale)


Ballard Site
OMW-16
OMW-18
OMW-15
OMW-7
OMW-2
OMW-3
OMW-1
OMW-14
OMW-9
OMW-10
OMW-19
OMW-5
OMW-11
OMW-6
OMW-12
OMW-21
OMW-22
OMW-23
INDIAN CREEK
BEAVER DAM ROAD
EDMONSTON ROAD
OMW-28
OMW-25
OMW-26
OMW-27
OMW-24
MW12
MW22:1-3
MW23:1-3
MW11:1-3
Former
BARC 6 Location
MW14
MW6
MW21
MW19
MW13
MW7
MW16:1-3
MW1
MW15
MW8
MW25:1-2
MW15R:1-3
MW2
USDA OFFICE
COMPLEX
MW9
MW4
MW3
MW10
WMATA
COMPLEX
MW18
MW17
INTERSTATE 95/495
CSX RAILROAD
EDMONSTON ROAD
BEAVER DAM CREEK
SCALE
0' 250' 500'
MW20:1-3
N
Figure 3.3.
Plan view of MODFLOW Assigned Gaps in Confining Layer (Layer 3) Between Deep Shallow Aquifers
BMT Designers & Planners
LEGEND
BARC6
BARC Baundary
Road
Creek
Building
Rail Road
Storm Water Retention Pond
Monitoring Well
Assigned Gap in aquifer confining layer
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495

3.1.2 Time Intervals

The groundwater model was programed to run on one-year time intervals from 1962 until 2010. Annual time steps were selected to simplify user specified, time variable inputs in the fate and transport model.

3.1.3 Groundwater Model Boundary Conditions and Water Storage Properties

The groundwater model grid is bound on all lateral borders by constant head cells that maintain a user-defined hydraulic head for fixed time interval of model operation. A lateral boundary comprised of constant head cells simulates groundwater movement into the groundwater model grid from upgradient and is useful for simulating steady state aquifers primarily fed by groundwater recharge. Constant head cell values were held constant for the duration of the model run. The model grid simulates the entire thickness of the observed aquifer within the groundwater model study area, and no vertical recharge from the surface or from below the model grid was simulated.

Over one-year time intervals, the groundwater model study area was assumed to be a steady state aquifer system with minimal changes in groundwater storage. Constant head cell values were derived from groundwater elevation data measured during a comprehensive well gauging event that was conducted in 2010. This well gauging event included all BARC 6 monitoring wells and off-site monitoring wells and was selected as the representative data set for conceptual model development. Constant head cell values were the same for layers 1, 2, and 3 for the duration of the model run. Constant head values in layer 4 were derived from groundwater elevation data measured in monitoring wells screened through the deep aquifer unit. Elevation measurements from these wells were generally a half meter greater than groundwater elevations within the shallow aquifer unit.

3.1.4 Hydraulic Conductivity

Hydraulic conductivity values were assigned to each conceptual model layer based on regional geologic data, observed lithology, aquifer testing results, and model calibration (Section 4). The vertical hydraulic conductivity assigned to each layer was set at one-tenth of the horizontal hydraulic conductivity for each layer. Laboratory research regarding fate and transport within aquifers has shown that most of the contaminant transport occurs within transmissivity zones defined by high hydraulic conductivity. In many cases, aquifer testing underestimates the hydraulic conductivity in these primary transport pathways (FRTR, 2013). As a result, hydraulic conductivity values that correspond to the primary transport pathways were assigned to each layer to more accurately represent contaminant migration.

The lateral extent of shallow aquifer layers 1 and 2 was divided into three contiguous zones with uniform hydraulic characteristics. The hydraulic conductivity values assigned to the shallow aquifer unit zones are: a) 10, b) 300 and c) 8,500 meters per year (0.09, 2.8 and 75 feet per day) and were verified through model calibration (Section 4). The horizontal extent of uniform hydraulic zones in model layers 1 and 2

are depicted in Figures 3.4 and 3.5, respectively. The horizontal extent of these layers was based on aquifer testing data that was discussed in Section 2.5, the horizontal extents of CAH contamination in groundwater and on geologic information was discussed in Section 2.4.

Within Layer 1, the lateral distribution of assigned hydraulic conductivity values was based on the CAH distribution patterns within the Groundwater Model Study Area. Observed CAH plumes do extend as far eastwards towards Indian Creek as would be predicted from groundwater contour maps alone. This suggests that groundwater formations within the streambed of Indian Creek are primarily composed of low hydraulic conductivity formations and that preferential groundwater pathways, comprised of high hydraulic conductivity formations are oriented primarily in a north-south direction. Overall extents within Layer 1 were based on the orientation of Indian Creek and surficial geology maps that were presented in Section 2.4

Within Layer 2, the lateral distribution of assigned hydraulic conductivity values was based on 2010 aquifer testing data and on groundwater model testing. Within MODFLOW, vertical differences in hydraulic conductivities effect the lateral direction of groundwater flow. Some adjustment was made with the lateral distribution of hydraulic conductivities within Layer 2 so that model derived groundwater elevation contours matched field data.

The values of 10 and 300 m/year were based on previous aquifer testing results that were described in Section 2.5. The value of 8,500 meters per year was derived from matching the historical extents of the CAH contaminant plume at different times within the groundwater model study area, these data points are discussed in Section 2.6. These values are assumed to represent bulk hydraulic properties for zones of effective solute transport within the groundwater model study area.

As indicated in Section 3.1.1, the hydraulic conductivity of the compact silt confining layer is considered 0. The assigned gaps within this layer have been assigned a hydraulic conductivity of 3,000 meters per year (27 feet per day). Horizontal hydraulic conductivity within layer 4 was set at 8,500 meters per year (75 feet per day) for the entire lateral extent of the layer.

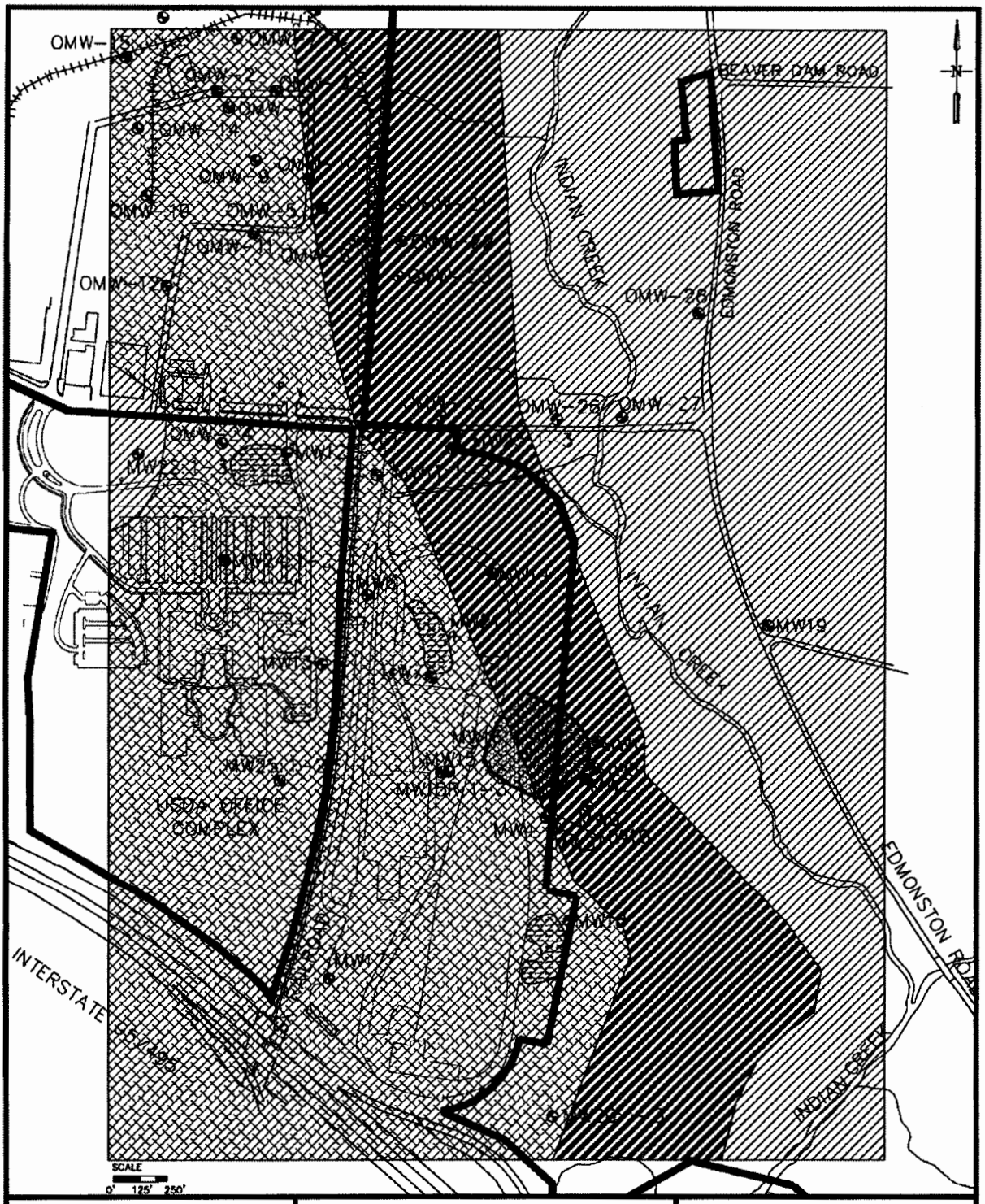


Figure 3.4.

Plan view of MODFLOW Layer 1 Horizontal Hydraulic Conductivity Distribution

BMT Designers & Planners

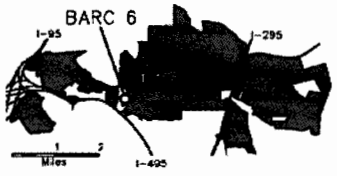
LEGEND

K = 75 feet per day

K = 2.8 feet per day

K = 0.09 feet per day

Beltsville Agricultural Research Center



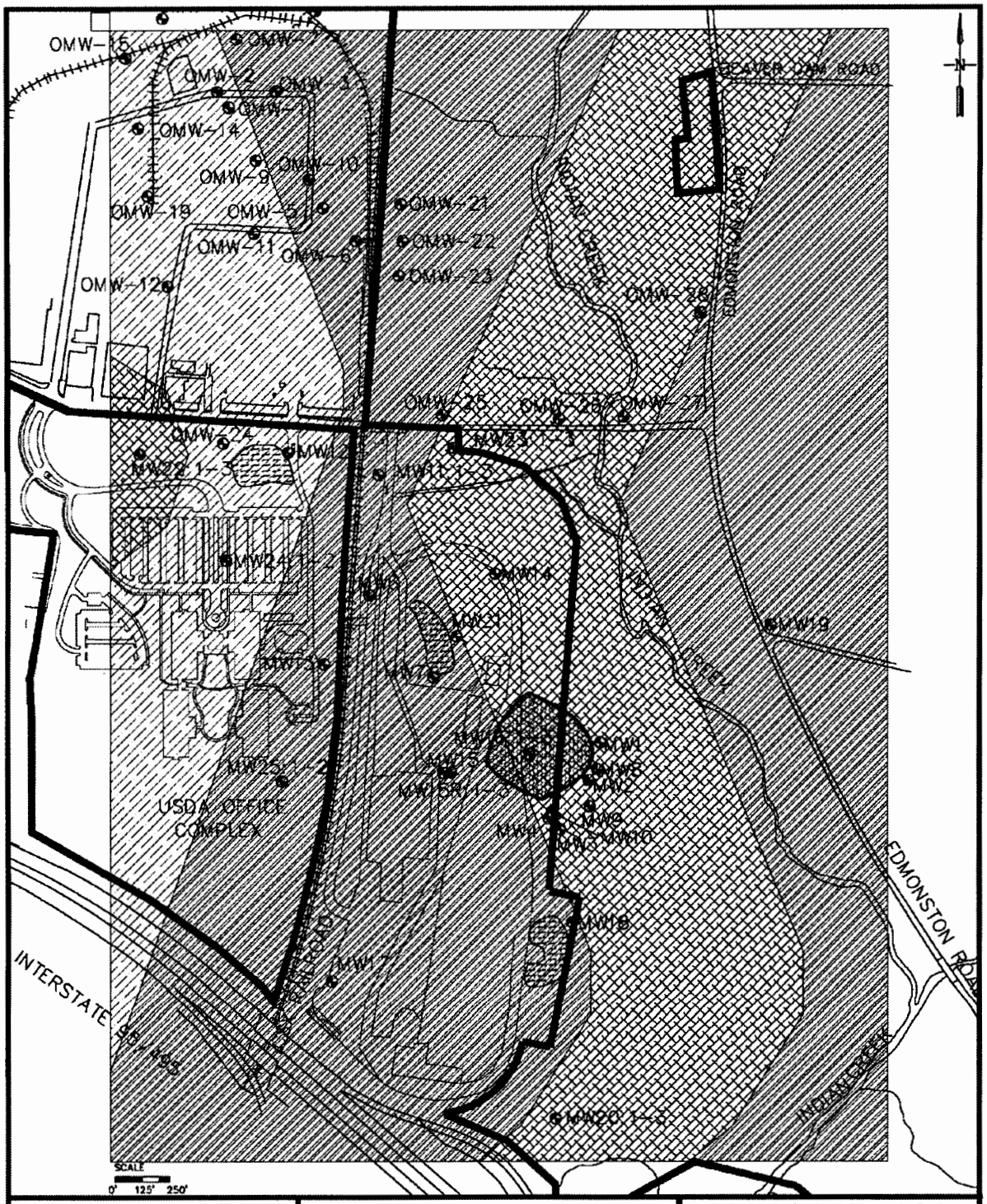


Figure 3.5.

Plan view of MODFLOW Layer 2 Horizontal Hydraulic Conductivity Distribution

BMT Designers & Planners

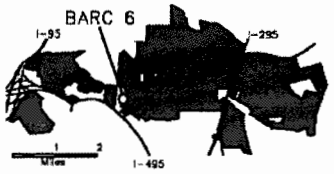
LEGEND

K = 75 feet per day

K = 4.5 feet per day

K = 0.9 feet per day

Beltsville Agricultural Research Center



3.1.5 Soil Bulk Density and Effective Porosity

Soil bulk density and effective soil porosity are user defined input parameters within MODFLOW model. These input parameters are used by the chemical reaction package of the RT3D model to calculate contaminant adsorption within the model space. Soil bulk densities can range from approximately 1,300 to 2,000 kg/m^3 for common aquifer matrix materials based on grain size, depth and level of compaction (Lovanh et al., 2000). Soil bulk density throughout the model grid was set at 1,600 kg/m^3.

Typical aquifer porosity values range from 0.2 to 0.4 (Hemond, 2000). Effective porosity is defined as the total volume of pore space within soil formation that allows fluid to flow through it. It is distinct from a total porosity which is a measure of the total volume of pore space within a soil formation as a fraction of the total volume of that formation. Effective porosity values can range from 0.2 to 0.35 for gravel and sandy formations in aquifers. A typical model-wide effective porosity value of 0.3 was selected for the MODFLOW model.

3.1.6 Surface Water Features and Inputs

Surface water features are described in Section 2.3. The hydrologic effects of both Indian Creek and Beaverdam Creek were simulated using the MODFLOW river package and included in the groundwater flow model. Both streams are considered gaining streams under normal flow conditions and grow wider as they flow downstream. As a result, the assigned values for river width and depth were progressively increased in the direction of water flow. Rainfall on all impervious surfaces within the study area is collected by storm water systems that drain into Indian Creek and then flows out of the groundwater model study area.

Surface water features and precipitation have a greater effect on groundwater flow over shorter time intervals and would need to be considered with a groundwater model run with time intervals of days or weeks. For a model using time steps of one-year in duration, groundwater inputs from precipitation and outputs from evapotranspiration were considered to have a negligible effect on the groundwater budget within the study area. As a result, for purposes of model development, precipitation inputs were considered negligible and not considered further in the development of the conceptual site model.

3.2. Conceptual Fate and Transport Model

The RT3D fate and transport model simulates three-dimensional, multi-species, reactive transport of chemical compounds (solutes) in groundwater through a user generated, three-dimensional groundwater flow model. The RT3D model contains pre-programmed reaction modules for simulating the dispersion and degradation chlorinated solvent plumes and also includes user generated values for several reaction mechanisms. The user defined input parameters used in the RT3D fate and transport model include source concentrations, reaction parameters, and dispersivity.

3.2.1 Time-Specific PCE Source Concentration

The RT3D model does not simulate the fate and transport of dense non-aqueous phase liquid (DNAPL) in groundwater. Rather, the RT3D model simulates contaminant migration based on a user defined time-specific dissolved phase concentration of a contaminant. This model input concentration is assumed to remain constant for an entire time step and is assumed to be uniform within a MODFLOW finite difference grid cell. For the BARC 6 fate and transport model, a single grid cell proximate to the location of the Ballard Site was selected as a source cell for PCE to simulate minor and major releases to the environment from 1965 to 1988. A user defined PCE concentration is assigned to this source cell for a single time step. The PCE source concentration was determined based on the history of the PCE releases and dissolved phase PCE concentrations detected in monitoring wells located at the Ballard Site (Ballard Site wells).

The Ballard Site was in operation from 1965 to 1988. A release of PCE on the order of several hundred gallons was reported to the Maryland Department of the Environment (MDE) in 1989. It was also reported that smaller scale releases occurred periodically during Ballard Site operations (MDE, 2007). Additionally, the presence of chlorinated solvents in the shallow groundwater around the BARC biodegradable site in the early 1990s is consistent with releases of PCE from the Ballard Site prior to the reported release in 1988. The distance from the Ballard Site to the Biodegradable Site is more than one kilometer (3,280 feet). The groundwater table is typically encountered at a depth of 10 to 12 meters (33 to 39 feet) below ground surface (bgs) in the area of the Ballard Site which suggests that underlying soils in the unsaturated zone containing DNAPL or adsorbed PCE may serve as a continuing source of groundwater contamination.

PCE was detected at a maximum concentration of 110,000 µg/L in Ballard Site well MW-11 in in 2003. PCE has a maximum solubility in water of 150,000 µg/L at 25 degrees Celsius (U.S. Dept. HHS , 1997). A soil vapor extraction (SVE) system was operated at the Ballard Site from November of 2002 to the summer of 2005 and an air sparging system operated from February of 2003 to the summer of 2005 (BMT Entech, 2006). As a result of remediation system operation, concentrations of PCE in Ballard Site

wells were reduced and a decreasing trend in PCE concentrations was observed in Ballard Site wells and downgradient OMWs. Groundwater monitoring data from the Ballard Site is provided in Appendix B.

Time-specific source concentrations of PCE were based on available historical data from the Groundwater Model Study Area and refined during the model calibration process, which is discussed at more length in Section 4.

3.2.2 Spatially Variable Reaction Parameters

The RT3D fate and transport model simulates the degradation of PCE through user defined first order decay rates for the aerobic and anaerobic biodegradation processes for CAHs. RT3D does include a user input defined parameter for abiotic degradation of PCE. Decay rates are estimated based on physical parameters, such as dissolved oxygen and oxygen-reduction potential, collected during field sampling and from spatial analysis of the concentration of PCE and related breakdown products within the groundwater study area.

Groundwater quality data collected downgradient of the Ballard Site since 1999 has revealed a plume with PCE concentrations greater than 1,000 µg/L and low concentrations of degradation products. This suggests that anaerobic biodegradation of PCE is minimal at the Ballard Site and the areas immediately downgradient. Groundwater quality data collected around the Biodegradable Site south of Sunnyside Avenue indicates that TCE and DCE are the primary groundwater contaminants with only low concentrations of PCE detected in this area. This suggests that dechlorination of PCE is occurring to a limited extent as the groundwater plume migrates and that further dechlorination of TCE to DCE is occurring to an even lesser extent. Vinyl chloride (VC) has historically not been detected in any monitoring wells within the study area, suggesting that dechlorination of DCE to VC is not occurring.

The RT3D fate and transport simulates the biodegradation PCE through anaerobic processes only. As a result, there is no user defined input for aerobic biodegradation or abiotic degradation of PCE. The RT3D PCE Biodegradation module includes user defined input parameters for the anaerobic and aerobic biodegradation of: TCE, DCE, VC and Ethene. Since vinyl chloride is not detected in groundwater, the biodegradation rates for DCE isomers to VC and for VC to ethene are 0 in the fate and transport model. The decay rates for the anaerobic degradation of PCE and the anaerobic degradation of TCE were included in the fate and transport model as user defined input parameters derived from published values for decay rates and model calibration (Section 4).

Based on groundwater quality data, the groundwater study area is considered to contain three distinct reaction zones within the shallow aquifer.

- An aerobic zone in the vicinity of the Ballard Property with negligible PCE biodegradation.
- An anaerobic zone with relatively high reaction rates immediately south of the aerobic zone where PCE degrades to TCE and DCE
- An anaerobic zone with relatively low reaction rates throughout the rest of the study area.

The extent of each zone was determined based on the spatial distribution of PCE and its degradation products in groundwater and was verified through model calibration (Section 4).

3.2.3 Dispersivity

Within most groundwater systems, there is a tendency for solutes to spread, laterally and vertically from the path that would be predicted by only be advective transport. This spreading phenomenon is called hydrodynamic dispersion. Values for longitudinal dispersivity as high as 100 meters have been used in mathematical simulations of large contaminant plumes in homogenous, sandy aquifers (Freeze and Cherry, 1979). Dispersion is defined in linear units, with higher values correlating to a greater lateral spread of solute within a groundwater system.

Field estimates for longitudinal dispersivity in large aquifers (more than 1,000 meters in scale) range from 20 to 900 meters with many aquifer systems having estimated longitudinal dispersivity values of 20-30 meters (Gelhar et. al, 1992). Field estimates for dispersivity in large aquifers were considered unreliable compared to estimates from smaller aquifer study areas due to the difficulty in establishing a sufficient number of sampling points over the almost 400 acre study area. A Longitudinal dispersivity of 40 ft (12 meters) was used for the MODFLOW and RT3D model to simulate a CAH plume at Dover Air Force Base within a groundwater model study area with similar scale and hydraulic conductivity (Clement et al, 1999).

During model calibration, longitudinal dispersivity values ranging from 12 to 50 meters (39 to 164 feet) were initially used. Values for transverse dispersivity (perpendicular to groundwater flow) and vertical dispersivity (downward from groundwater flow) are typically one-tenth and one-hundredth the magnitude of the value for longitudinal dispersivity, respectively. Spatially variable dispersivity values can also be programmed into the RT3D model.

Research into the spread of large and dilute plumes by tracer studies has revealed the near absence of mechanical dispersion as a mechanism for transversely spreading dissolved contaminants lateral to the flow of groundwater (Gelhar et. al, 1992). What is observed as mechanical dispersion, is likely slight temporal variations in primary groundwater flow directions biasing the flow of contaminants into different preferential pathways within a complex hydrogeologic system. Transverse mechanical dispersion as a computer model input is a general approximation for these slight variations in primary groundwater flow direction which would be much more difficult to accurately simulate. Higher model inputs for transverse

dispersivity would correspond to a groundwater flow regime with large variations in the primary groundwater flow direction over time.

3.2.4 Adsorption

The retardation of dissolved phase CAHs influences their fate and transport in the environment and can be accounted for in the RT3D fate and transport model. The RT3D model includes physical properties of CAHs but relies on user-defined input parameters including soil bulk density, soil porosity, and sorption capacity to determine retardation. Soil bulk density and porosity were selected based on published values (Section 3.1.5).

The sorption capacity of soil is dependent on a series of properties, which are grain-size distribution, specific surface area, cation exchange capacity, pH, organic matter or organic carbon content, and mineral constituents (NIST, 2000). Due to the heterogeneity of the subsurface within the study are, these parameters are expected to be highly variable and site-specific values are not available. As a result, sorption capacity values for PCE and its degradation products were determined by model calibration. Model calibration primarily considered the distribution of PCE, specifically its presence in high concentrations in groundwater within the Beltsville Industrial Park and lower concentrations observed in groundwater south of Sunnyside Avenue.

Within the RT3D fate and transport model, retardation is simulated by one of three types of adsorption that are based on user defined inputs. Sorption values can be programed to be spatially variable within the groundwater model study area. The three potential types of adsorption are described below.

Linear Isotherm (equilibrium): This sorption option calculates retardation based on the following formula.

$R = 1 + rbK_D / n$

where:

rb = bulk density

K_D = (soil) distribution coefficient = foc Koc

foc = fraction organic carbon

Koc = organic carbon/water partition coefficient. Koc is typically expressed in liters per kilogram (L/kg) and has been derived from laboratory testing over a range of formations.

Koc is CAH specific. Koc values of 265, 94 and 65 L/kg for selected for PCE, TCE and DCE respectively, based on published values in EPA guidance documents (EPA, 1996).

Freundlich Isotherm (nonlinear, equilibrium): This sorption option calculates retardation based on the following formula

$R = 1+rb/n*a*C^{a-1} *K_F$

Where:
rb = bulk density
K_F = the Freundlich constant expressed in L/kg
a = the Freundlich exponent
C = the concentration of the specific contaminant within the grid cell at the beginning of the time step.

Freundlich Isotherm (nonlinear, equilibrium) sorption increases with increasing contaminant concentration within a specific grid cell. K_F and a are both user inputs for this sorption module.

Langmuir Isotherm (nonlinear, equilibrium): This sorption option calculates retardation based on the following formula

$R = 1+rb/n*(K_L * S)/(1+K_L * C)$

Where:
rb = bulk density
K_L = the Langmuir constant in L/kg
S = The maximum amount of solute that can be adsorbed by the soils within a grid cell
C = the concentration of the specific contaminant within the grid cell at the beginning of the time step.

Langmuir Isotherm (nonlinear, equilibrium) sorption decreases over a certain maximum contaminant concentration. K_L and S are both user inputs for this sorption module.

Laboratory tests that were conducted to measure actual adsorption of PCE and TCE revealed that the sorption of both of these CAHs most closely matched sorption calculated using linear and Freundlich isotherms. Based on calculations, PCE and TCE have minimum values for foc for which organic carbon servces as a primary sorbent. These values are 0.0010 for PCE and 0.0021 for TCE (Ruffino & Zanetti 2009).

Model simulations were run using the Linear Isotherm sorption module due to the fact that values for K_D can be based on known published values and foc values can be based on analytical results for total organic carbon (TOC) in soils that have been collected in soils at the BARC Facility.

4. MODEL SIMULATIONS AND PARAMETER CALIBRATION

Both the groundwater flow model and dissolved contaminant fate and transport model required operational iterations to calibrate model input parameters against observed groundwater quality data from the study area. Calibration runs were conducted on both the groundwater flow model and the fate and transport model concurrently in recognition that groundwater model parameters such as hydraulic conductivity and constant head cell values affect the extent of the simulated contaminant plumes.

4.1 MODFLOW Groundwater Model Calibration

Groundwater elevation contours generally follow site topography with groundwater flowing toward areas of lower elevation on the banks of Indian Creek. Changes in groundwater flow direction and gradient in the MODFLOW generated groundwater elevation contours are influenced by constant head cell values at the study area boundaries, lateral differences in hydraulic conductivities, and surface water hydrology.

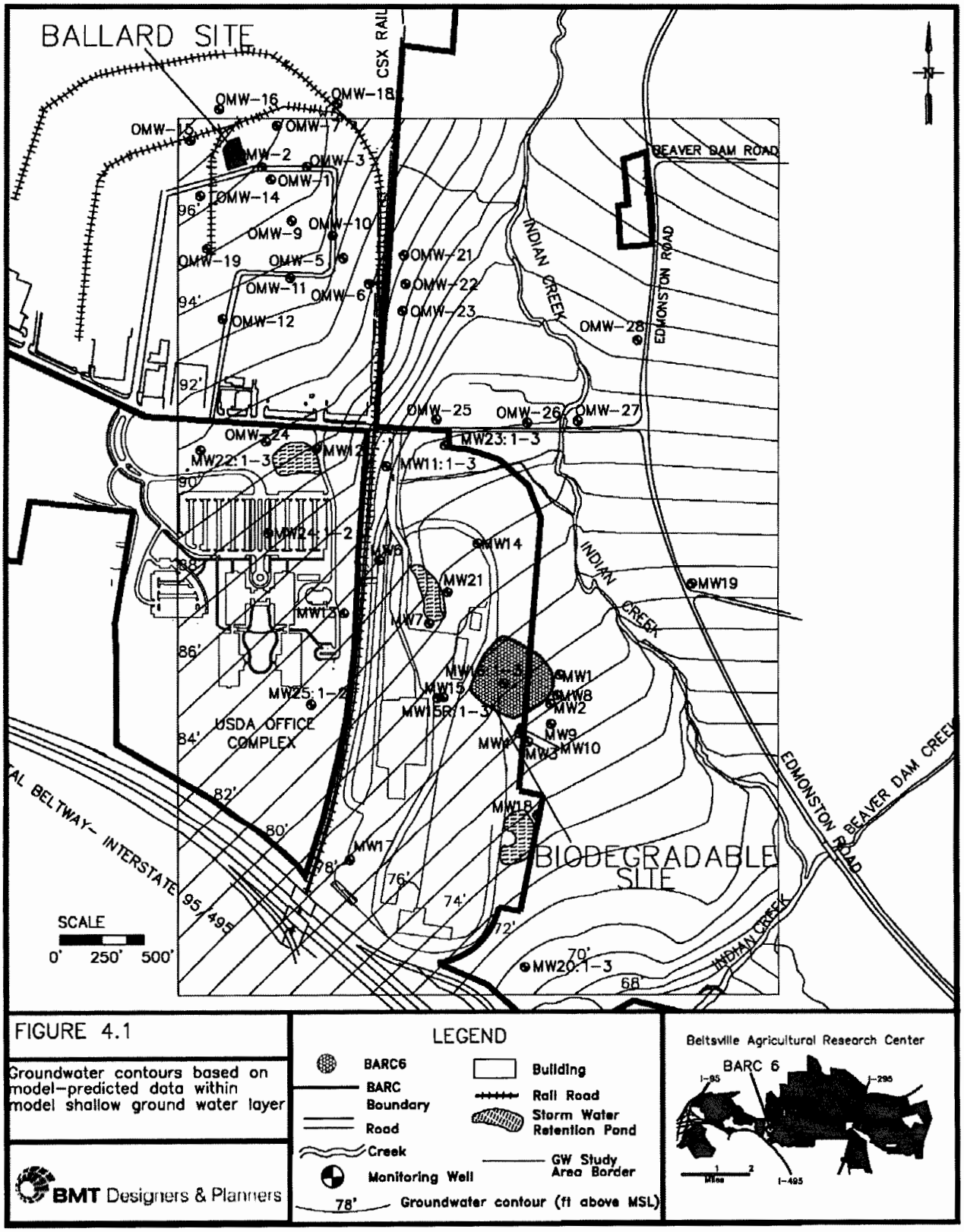
4.1.1 Calibration of Boundary Conditions

Values for constant head cells were derived from groundwater elevation measurements collected during a comprehensive well gauging event in 2010 that included all Biodegradable Site monitoring wells and all Ballard Site OMWs in the Beltsville Industrial Park. Constant head cells for the study area are consistent with observed groundwater elevations.

As indicated in Section 2.5, Indian Creek is considered a gaining stream. As a result, Indian Creek was assigned river head values (groundwater elevation within the stream) that were set approximately 3 to 5 inches above the hydraulic head values in the surrounding ground to reflect gaining stream conditions for Indian Creek. Input parameters for the stream package in MODFLOW are discussed in Section 3.1.6. Stream width was set at 3 meters at northern boundary of the groundwater model study area and 3.6 meters at the southeastern boundary. River bed thickness was set at 1 meter and river bed hydraulic conductivity was set at 365 meters per year.

A portion of Indian Creek, after merging with Beaverdam Creek flows southwest within the southeastern corner of the groundwater model study area. Based on field observations from surface water sampling events, the "River Width" variable was set at 6 and 6.25 meters at the upgradient and downgradient boundaries of this portion of the stream, respectively.

The MODFLOW generated groundwater elevation contours for the shallow aquifer unit approximate groundwater flow direction and gradient within the groundwater study area. The MODLFOW generated groundwater elevation contours are presented in Figure 4.1, and are consistent with observed groundwater elevations (Figure 2.6).


BALLARD SITE
CSX RAIL
BEAVER DAM ROAD
INDIAN CREEK
EDMONSTON ROAD
OMW-16
OMW-18
OMW-17
OMW-15
OMW-2
OMW-3
OMW-1
OMW-14
OMW-9
OMW-10
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MW14
MW8
MW21
MW19
MW13
MW7
MW16:1-3
MW1
MW15
MW8
MW25:1-2
MW15R:1-3
MW2
USDA OFFICE COMPLEX
MW9
MW10
MW3
MW18
MW17
BIODEGRADABLE SITE
MW20:1-3
BELTWAY- INTERSTATE 95/495
EDMONSTON ROAD
BEAVER DAM CREEK
INDIAN CREEK
96'
94'
92'
90'
88'
86'
84'
82'
80'
78'
76'
74'
72'
70'
68'
SCALE
0' 250' 500'
N
FIGURE 4.1
Groundwater contours based on model-predicted data within model shallow ground water layer
BMT Designers & Planners
LEGEND
BARC6
BARC Boundary
Road
Creek
Monitoring Well
78' Groundwater contour (ft above MSL)
Building
Rail Road
Storm Water Retention Pond
GW Study Area Border
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495
Miles

The MODFLOW groundwater model also generates a groundwater elevation contour for the deep aquifer unit (model layer 4). Since there is no surface water influence on the deep aquifer unit and the hydrologic properties of the deep aquifer unit are assumed to be uniform, the only parameter affecting the MODFLOW generated groundwater contours are the constant head cells used to define boundary conditions. The constant head cell values were determined based on observed groundwater elevations during the 2010 monitoring well gauging event (Figure 2.9). The MODLFOW generated groundwater elevation contour for the deep aquifer unit is presented in Figure 4.2.

4.1.2 Hydraulic Conductivity Calibration

Values for horizontal hydraulic conductivity were based on previous aquifer testing data for Indian Creek stream bed and the Biodegradable Site wetlands. Bulk horizontal hydraulic conductivity, in the shallow aquifer unit, within the western portion of the groundwater model study area were estimated based on historical groundwater contamination data that was presented in Section 2.6. The extents of the PCE and TCE plumes were used to arrive at an estimated hydraulic conductivity of 8,500 meters per year (75 feet per day) for the presumed preferential pathways between the Ballard Property and the Biodegradable Site. This value is a rough estimate of the bulk properties of this area within the shallow aquifer unit which includes zones of high and low hydraulic conductivity that may not be contiguous within the entire extent of the groundwater model study area.

Model iterations with were run with hydraulic conductivities, within the high conductivity zones ranging from 2,500 meters per year (22.5 ft/day) to 15,000 meters per year (135 ft/day) during initial parameter calibration. A bulk horizontal hydraulic conductivity of 2,500 meters within the high conductivity zone of the shallow aquifer resulted in PCE and TCE plumes that did not extend south of Sunnyside Avenue within the model time scales. A bulk hydraulic conductivity of 15,000 meters per year resulted in PCE plumes that extended much further than south than plume extents predicted from observed data.

Hydraulic conductivity within the deep aquifer unit was set at the 8,500 meters per year throughout this model layer. No reliable aquifer testing data was available for this formation and limited contaminant plume data is available to make estimates of travel time velocity. Groundwater velocity is calculated using the following equation

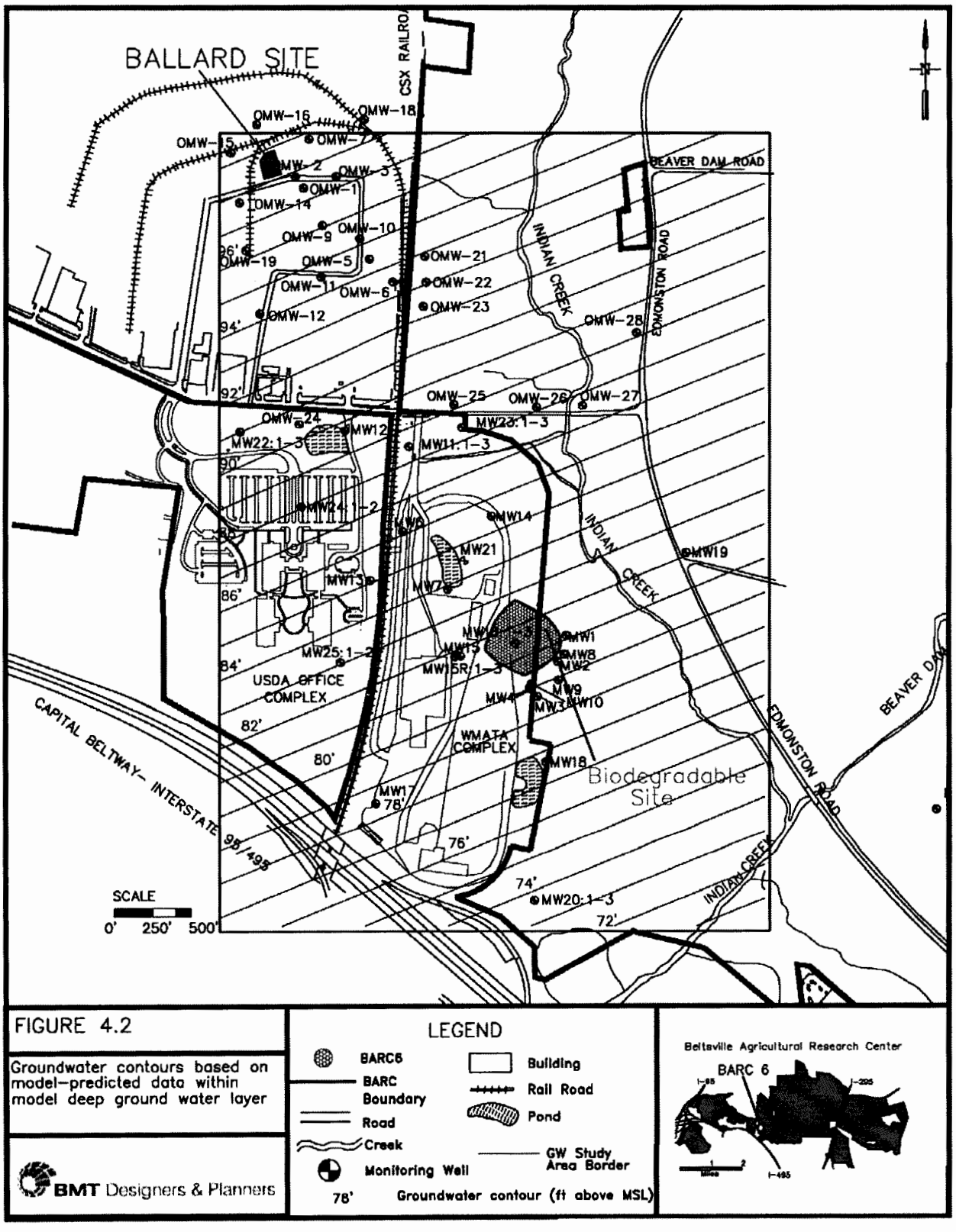
$$v = K i / n$$

where:

K = hydraulic conductivity

i = hydraulic gradient

n = porosity


BALLARD SITE
CSX RAILRO
OMW-16
OMW-18
OMW-15
OMW-17
MW-2
OMW-3
OMW-1
OMW-14
OMW-9
OMW-10
OMW-19
OMW-5
OMW-21
OMW-11
OMW-6
OMW-22
OMW-23
OMW-12
OMW-28
BEAVER DAM ROAD
INDIAN CREEK
EDMONSTON ROAD
OMW-25
OMW-26
OMW-27
OMW-24
MW12
MW23:1-3
MW22:1-3
MW11:1-3
MW24:1-2
MW14
MW21
MW19
MW13
MW7
MW1
MW8
MW2
MW25:1-2
MW15R:1-3
MW9
MW4
MW3
MW10
USDA OFFICE COMPLEX
WMATA COMPLEX
MW18
Biodegradable Site
MW17
MW20:1-3
CAPITAL BELTWAY- INTERSTATE 95/495
SCALE
0' 250' 500'
FIGURE 4.2
Groundwater contours based on model-predicted data within model deep ground water layer
BMT Designers & Planners
LEGEND
BARC6
BARC Boundary
Road
Creek
Monitoring Well
78' Groundwater contour (ft above MSL)
Building
Rail Road
Pond
GW Study Area Border
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495

Assuming a porosity value of 0.3 and hydraulic gradient values of 0.0056 to 0.011 feet per foot (ft/ft) (section 2), produces a groundwater velocity range of 159 to 312 meters per year, or 1.4 to 2.7 feet per day.

Vertical hydraulic conductivity was held constant at one-tenth the value of horizontal hydraulic conductivity during all groundwater model calibration runs. The radio of horizontal to vertical hydraulic conductivity can vary by orders of magnitude depending on the scale of the sampled aquifer. Horizontal to vertical hydraulic conductivity ratios (K_H/K_V) of 2.4 to 8.3 have been measured in small scale (several feet) tracer simulation studies, and K_H/K_V ratios of up to 1,000 have been estimated within large-scale regional groundwater flow systems (Kenoyer, 1988). The K_H/K_V ratios are difficult to measure as pumping tests, slug tests using numerical models will all yield different results (Kenoyer, 1988). A model wide K_H/K_V ratio of 10 was selected to simplify the model calibration process. K_H/K_V ratios of 10 are commonly used in MODFLOW simulations (Simcore Software, 2012).

4.2 RT3D Fate and Transport Model Calibration

The observed CAH plume extends form the Ballard Site to the southern extent of the groundwater model study area. The highest concentrations of CAHs are located in the northern portion of the groundwater model study area immediately downgradient of the Ballard Site. An air sparging/soil vapor extraction system was operated at the Ballard site beginning in 2002. The extent of contamination in the groundwater model study area is described in Section 2.6. User defined fate and transport model input parameters were calibrated using observed contaminant concentrations in source and downgradient monitoring wells. The data sources used to calibrate the fate and transport model are discussed below:

4.2.1 Dispersivity

As described in Section 3, dispersivity is a process whereby a dissolved solvent will be spatially distributed through a saturated aquifer. During model calibration, a range of longitudinal dispersivity values of 12 to 50 m (39 to 164 feet) were used to evaluate the effect on plume extent. Values higher than 50 meters resulted in very wide plumes that extended past the westward boundary of the groundwater model study area and well east of Indian Creek. Lower dispersivity values resulted in a plume that was far narrower than observed plume spread.

Values for transverse dispersivity (perpendicular to groundwater flow) and vertical dispersivity (downward from groundwater flow) were set at one-fifth and one-fiftieth of the longitudinal dispersivity value, respectively. Dispersivity values outside of the upper end of this range resulted in plume extents that did not match observed CAH concentrations in monitoring wells located east of Indian Creek and in the western extent of the Beltsville Industrial Park.

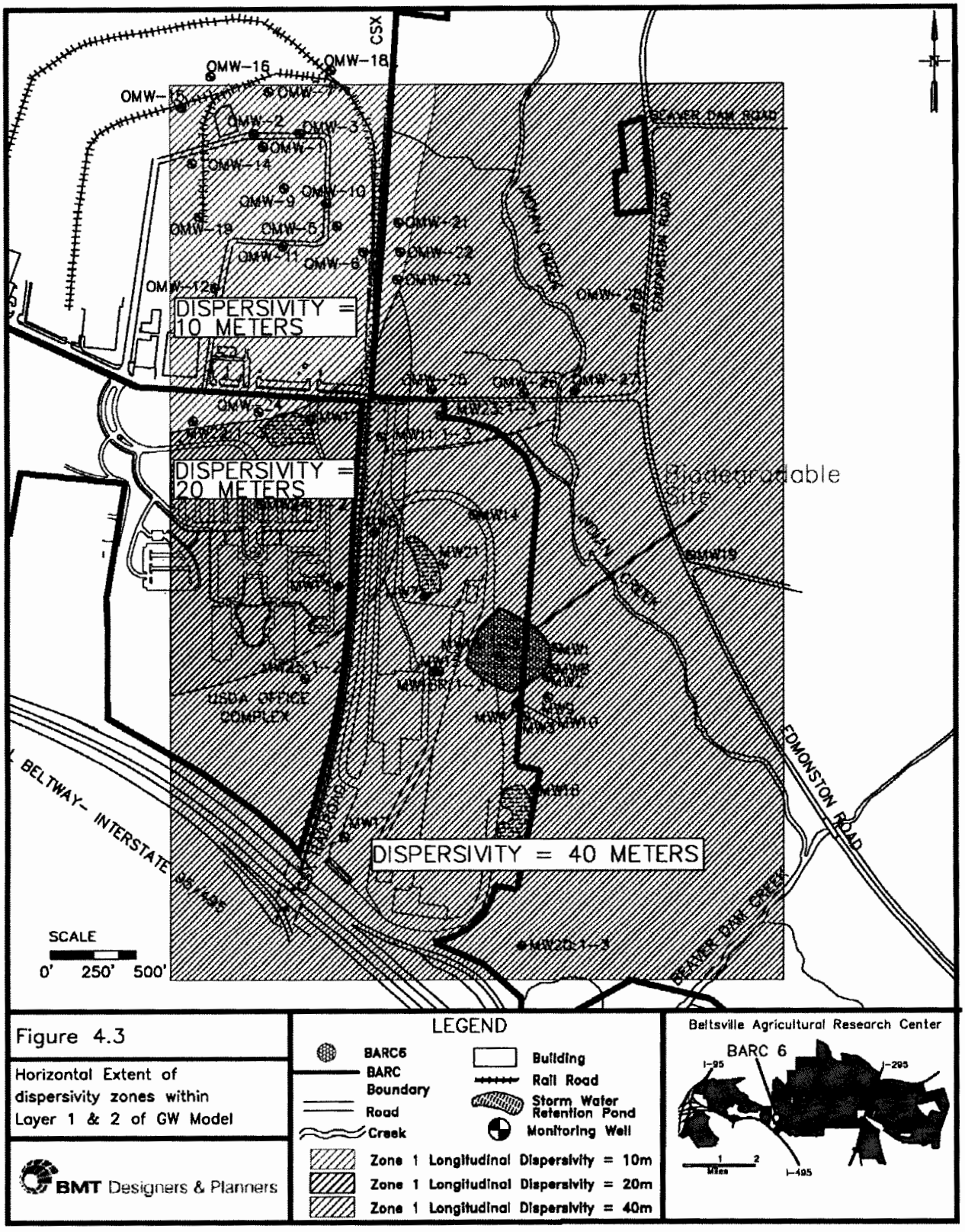
Spatially variable values for longitudinal dispersivity were used in the final model to match observed plume results. The extent of the PCE plume, between the Ballard Property and the railroad tracks to the east suggest a very low value for dispersivity in the vicinity of the Ballard Property. The wide extent of the TCE plume between the USDA Carver Center and the Biodegradable Site suggest a much higher longitudinal dispersivity south of Sunnyside Avenue. This may be attributable to a greater number of preferential pathways for the CAH plume to spread at an increasing distance from the Ballard Site.

Final model-wide dispersivities of 10 m (33 feet), 20 m (66 feet) and 40 meters (132 feet) was selected for the groundwater model fate and transport simulations and is consistent with values for dispersivity that have been used in RT3D PCE spread and biodegradation models of spatial and temporal scales as this model does (Clement et al. 1999). The horizontal extents of zones of fixed dispersivity within the groundwater model study area are presented in Figure 4.3.

4.2.2 Contaminant Biodegradation Rates

RT3D simulates the degradation of PCE by assigning a user defined first-order decay rate to PCE and its' degradation products. As indicated in Section 3.2.2, the development of the conceptual model identified three discrete zones of biodegradation within the shallow aquifer unit corresponding to aerobic degradation, anaerobic degradation, and a transition zone. First order decay rates based on published values were assigned to PCE and TCE for each zone and were calibrated using site specific groundwater quality data. A first order decay rate of 0 was assigned to DCE for all zones because its degradation product, vinyl chloride, has not been detected at in groundwater within the groundwater model study area. The geographic extent of these homogenous biodegradation zones was derived from analyzing the spatial distribution of PCE and its degradation products in groundwater.

Within the Beltsville Industrial Park, very high concentrations of PCE (greater than 1,000 µg/L) were detected at OMW-1, OMW-2, OMW-5 and OMW-10 with correspondingly low (less than 10 µg/L) concentrations or non-detections of TCE and DCE within the same wells. A tag map depicting concentrations of CAHs in off-site monitoring wells is presented in Section 2 (Figure 2.10). This suggests that conditions within the Beltsville Industrial Park are not conducive for the biodegradation of PCE. As a result, first order decay rates corresponding to aerobic conditions were assigned to this zone. Dissolved oxygen (DO) and oxidation-reduction-potential (ORP) readings that were collected from low flow sampling OMWs within the Beltsville Industrial Park revealed consistently high levels of DO in groundwater and high (over +100mV) ORP readings (BMT, 2010). High DO and ORP readings are both indicative of groundwater conditions not conducive to the reductive dechlorination of CAH compounds.


CSX
OMW-16
OMW-18
OMW-15
OMW-17
OMW-2
OMW-3
OMW-1
OMW-14
OMW-9
OMW-10
OMW-19
OMW-5
OMW-11
OMW-6
OMW-12
OMW-21
OMW-22
OMW-23
OMW-25
BEAVER DAM ROAD
DISPERSIVITY = 10 METERS
OMW-24
OMW-26
OMW-27
MW23-1-3
MW11-1-3
MW24-1-3
DISPERSIVITY = 20 METERS
Biodegradable Site
MW14
MW21
MW7
MW19
MW25-1-2
USDA OFFICE COMPLEX
MW8SR1-2
MW1
MW2
MW3
MW10
MW18
MW17
DISPERSIVITY = 40 METERS
BELTWAY- INTERSTATE 95/495
EDMONSTON ROAD
MW26-1-3
BEAVER DAM CREEK
SCALE
0' 250' 500'
N
Figure 4.3
Horizontal Extent of dispersivity zones within Layer 1 & 2 of GW Model
BMT Designers & Planners
LEGEND
BARC6
BARC Boundary
Road
Creek
Building
Rail Road
Storm Water Retention Pond
Monitoring Well
Zone 1 Longitudinal Dispersivity = 10m
Zone 1 Longitudinal Dispersivity = 20m
Zone 1 Longitudinal Dispersivity = 40m
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495
1
2
Miles

Downgradient of the Ballard Site across Sunnyside Avenue, concentrations of TCE in monitoring wells are greater than PCE concentrations (Figure 2.10). This suggests that conditions are favorable for the anaerobic biodegradation of PCE in this area. Based on groundwater quality data, TCE is the CAH present at the greatest concentrations in this area as a result of the biodegradation of PCE. This transition area is assigned the highest contaminant biodegradation rates.

Observed concentrations of PCE, TCE and DCE throughout the rest of the groundwater model study area indicate that biodegradation of TCE is occurring to limited extent and the degradation of DCE is not occurring. Additionally, geochemical data collected during the RI indicate that conditions are not conducive to the complete biodegradation of CAHs in this area (BMT Entech, 2004). TCE has consistently been detected at the highest relative concentrations in groundwater samples in Biodegradable Site monitoring wells since 1998. 1,1-DCE is typically detected at concentrations of approximately two-thirds the concentration of TCE within Biodegradable Site monitoring wells (Figure 2.10). This suggests that biodegradation rates for TCE are relatively low south of Sunnyside Avenue as it would be predicted that DCE would be detected at higher relative concentrations in downgradient monitoring wells, such as BA6-MW20 in a groundwater system with higher first-order decay rates for TCE. This area is assigned anaerobic biodegradation rates lower than the transition are and greater than the Beltsville Industrial Park Area.

Calibration of the biodegradation rates was conducted concurrently with the model calibration of the PCE time specific source concentration (Section 4.2.4). PCE and TCE biodegradation rates were calibrated by comparing the extents of the TCE and DCE plume against observed results from groundwater sampling. A plume of DCE with increasing concentrations down gradient of the biodegradable site indicated a TCE biodegradation rate that was too high while a plume of PCE that extended well past MW20 indicated that PCE biodegradation rates were set too low.

Based on the limited groundwater quality data from the deep aquifer unit, the deep aquifer unit was assigned uniform biodegradation rates for PCE and TCE covering the horizontal extents of the groundwater model study area. PCE and TCE biodegradation raters were determined based on the presence of TCE and DCE in the deep aquifer unit and their relative abundance compared to the shallow aquifer unit. The assigned anaerobic degradation rate for PCE corresponds to the anaerobic degradation rates in downgradient area because PCE is detected at low relative concentrations. The assigned anaerobic degradation rate for TCE corresponds to the anaerobic degradation rate in the transition zone because TCE is the CAH present in the highest relative concentrations, showing a similar pattern to CAH concentrations within the shallow aquifer unit, south of Sunnyside Avenue. The low biodegradation rates for PCE and TCE within Zone 3 is consistent with observations concerning monitored natural attenuation (MNA) of PCE and TCE from the RI Report (BMT, Entech 2004).

A map showing the location of the model simulated biodegradation zones is provided in Figure 4.4. First order decay rates for contaminant biodegradation used as contaminant fate and transport model input parameters are presented in Table 4.1.

Table 4.1 Model Assigned First-Order Decay Rates by Homogenous Area

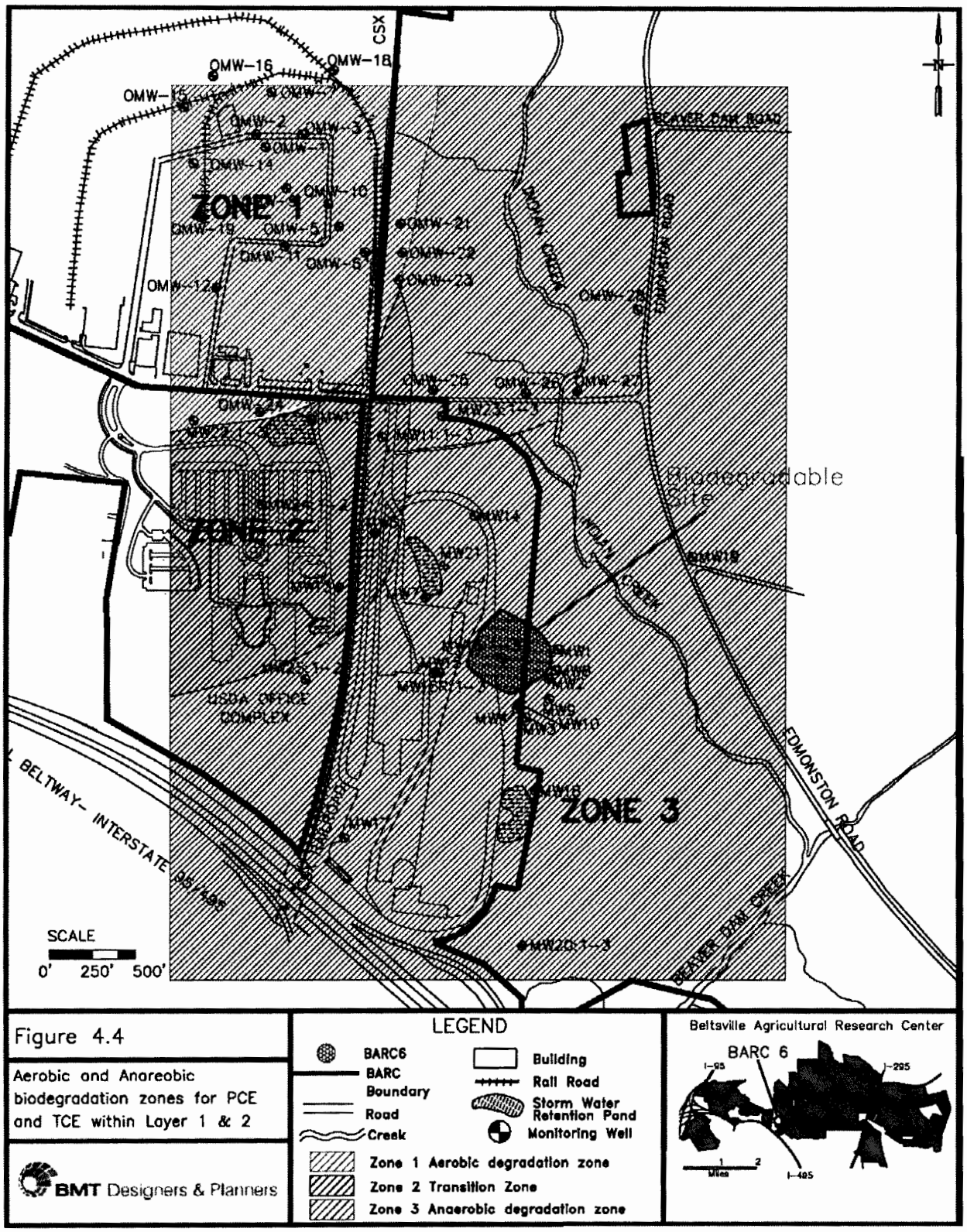
Biodegradation Rates					
First-order rate constant	Associated contaminant	Zone 1	Zone 2	Zone 3	Deep Aquifer
K1 (anaerobic)*	PCE	0.005	0.50	0.18	0.18
K2 (anaerobic)*	TCE	0.00	0.10	0.05	0.05
K3 (aerobic)*	TCE	0.01	0.00	0.00	0.00
*Biodegradation rate constants in 1/year					

4.2.3 Adsorption

The RT3D adsorption options were discussed in section 3.2.4. Linear Isotherm adsorption parameters were used on model simulations, but the resulting model generated plumes had a far more limited extent than observed plume extents within the groundwater model study area. Final groundwater model calibration simulations were run with no programed adsorption for PCE, TCE or DCE. As stated in Section 3.2.4, there are calculated threshold values for the organic carbon fraction in soils (foc) that induce measureable retardation in groundwater systems. Based on boring logs, the majority of the soils within the groundwater model study area contains negligible quantities of organically available carbon that are likely to be less than threshold foc values (Appendix A). Groundwater and contaminant transport within the groundwater model study is presumed to occur within layers comprised of coarse sands and gravel, with very limited potential for adsorption. Further discussion of adsorption within the groundwater model is presented in Section 4.3.

4.2.4 PCE Source Concentration

As indicated in Section 1, the release at the Ballard Site was reported in 1988 and other releases are reported to have occurred during Ballard Site operation dating back to 1965 due to minor spills and leaking storage tanks (MDE, 2007). An air-sparging/soil vapor extraction system (AS/SVE) system was in operation from 2002 to 2005. Ballard Property on-site and off-site monitoring wells were sampled as part of a regular groundwater monitoring program from 1999-2005. A significant increase in PCE concentrations was measured in 2004 within off-site monitoring wells that were located directly downgradient of the Ballard Property.


CSX
OMW-16
OMW-18
OMW-17
OMW-2
OMW-3
OMW-1
OMW-14
OMW-10
ZONE 1
OMW-19
OMW-5
OMW-11
OMW-6
OMW-12
OMW-21
OMW-22
OMW-23
OMW-28
BEAVER DAM ROAD
EDMONSTON ROAD
BEAVER DAM CREEK
S2-1
OMW-24
OMW-25
OMW-26
OMW-27
MW23 1-3
MW11 1-3
Biodegradable Site
ZONE 2
MW14
MW21
MW19
MW5
MW7
MW1
MW2 1-2
USDA OFFICE COMPLEX
MW3
MW16
ZONE 3
MW18
MW17
BELTWAY- INTERSTATE 95/495
MW20 1-3
SCALE
0' 250' 500'
N
Figure 4.4
Aerobic and Anaerobic biodegradation zones for PCE and TCE within Layer 1 & 2
BMT Designers & Planners
LEGEND
BARC6
BARC Boundary
Road
Creek
Building
Rail Road
Storm Water Retention Pond
Monitoring Well
Zone 1 Aerobic degradation zone
Zone 2 Transition Zone
Zone 3 Anaerobic degradation zone
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495
1
2
Miles

The time-specific PCE source concentration is a user-defined input parameter for the RT3D model that was determined through model calibration considering available groundwater quality data from the groundwater model study area, the history of the release and remediation at the Ballard Site, and the history of the Biodegradable Site.

Groundwater quality data from the Ballard Site is only available dating back to 1989 at the Ballard Site and 1990 in the vicinity of the Biodegradable Site. Steady state to decreasing levels of chlorinated solvents within the wetlands around the Biodegradable Site between 1992 and 2010 suggests that releases of PCE at the Ballard Property occurred prior to the reported release in 1989.

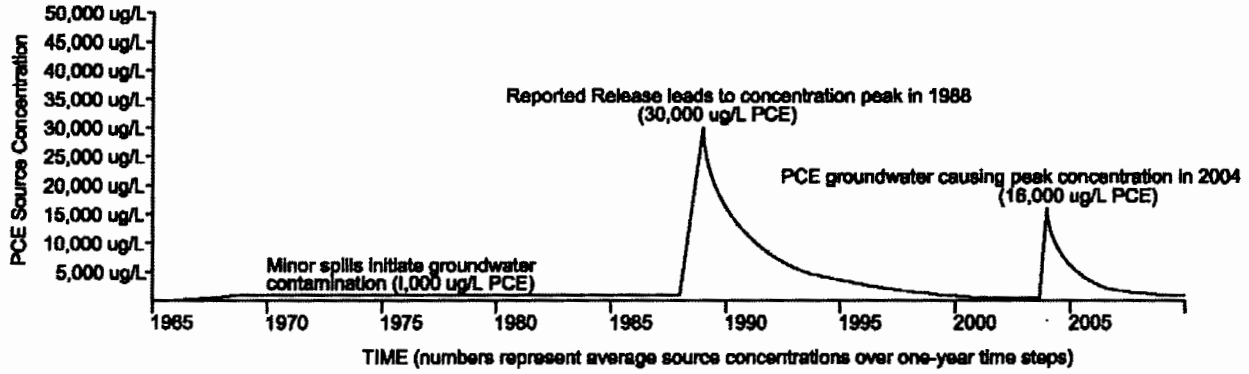
Several model iterations were run to test combinations of source concentrations and time release dates against observed contaminant concentrations at specific locations over time. Time specific source concentration patterns are shown below with a description of their overall simulated fate and transport results. All simulations were run on a model with the same hydraulic conductivity, dispersivity, and chemical reaction parameters. Based on available groundwater monitoring data, PCE concentrations in groundwater 'spiked' at the Ballard Property in 2004 and have steadily decreased until present day (Appendix B).

Earlier releases at the Ballard Property were simulated by assigning a fixed concentration of 1,000 to 3,000 µg/L to the Ballard Site from 1968 to 1988. A concentration of 1,000 µg/L, within the source concentration cell, is the equivalent to 300 grams of PCE within this cell assuming 30% pore space. The input of a few kilograms of PCE annually could maintain this concentration at the source cell.

PCE source concentration values were calibrated to address two 'peaks' in PCE source concentration, one in 1989, and one in 2004, corresponding to the original reported release of PCE and the observed 'spike' in PCE concentrations that was observed at the Ballard Property in 2004. PCE source concentrations were calibrated by running model simulations with the same hydrologic and chemical parameters but with different values for the pre-release, first concentration peak and second concentration peak. PCE source concentration runs were evaluated by comparing the simulated PCE, TCE and DCE extents against observed groundwater sampling results. PCE source concentrations of 150,000 µg/L (solubility limit of PCE in water) at the time of the reported PCE release, were used for initial model calibration, but these source concentrations resulted in CAH plumes that were far more extensive than observed plumes at the site. PCE 'peak' source concentration patterns over the 1965 to 2010 are shown in Figure 4.5 and in Table 4.2

PCE source concentrations at the second peak were based on observed PCE concentrations within OMW-2 from 2002 through 2005.

Figure 4.5 Groundwater Model PCE Source Concentrations over Simulated Time



As stated in Section 3, the RT3D source concentration module allows the input of a user defined PCE source concentration within in or more MODFLOW grid cells for each model time step. A PCE source concentration of 3,000 µg/L within RT3D simulates a cell with a uniform and constant PCE concentration of 3,000 µg/L for the duration of the time step.

The peak concentrations of 30,000 and 16,000 µg/L used in the groundwater model are less than peak PCE concentrations that were detected in Ballard Site monitoring wells between 1989 and 2005, and are therefore likely to represent a conservative estimate of the total volume of PCE released at the Ballad Property.

4.3 Sensitivity Analysis

Model calibration involved perturbing PCE source concentrations, chemical biodegradation rates and hydraulic conductivity values in an iterative process. Groundwater model predicted extents and concentrations for the PCE, TCE and DCE plumes at various points between 1998 and present day were compared against observed groundwater concentrations in monitoring wells within the groundwater model study area at the same time. These concentration patterns are discussed in Section 2.6

During model calibration, model sensitivity to the following parameters was evaluated:

- Chemical Biodegradation Rates
- Time Specific Source Concentration
- Adsorption

The effects of changing these parameters are discussed below.

Table 4.2 PCE Groundwater Model Time Specific PCE Source Concentration

TIME			
MODEL YEAR	CALENDAR YEAR	SOURCE PCE (µg/L)	NOTES:
1	1962	0	
2	1963	0	
3	1964	0	
4	1965	0	
5	1966	500	Year after operations commence at Ballard Property
6	1967	750	
7	1968	1,000	
8	1969	1,000	
9	1970	1,000	
10	1971	1,000	
11	1972	1,000	
12	1973	1,000	
13	1974	1,000	
14	1975	1,000	
15	1976	1,000	
16	1977	1,000	
17	1978	1,000	
18	1979	1,000	
19	1980	1,000	
20	1981	1,000	
21	1982	1,000	
22	1983	1,000	
23	1984	1,000	
24	1985	1,000	
25	1986	1,000	
26	1987	1,000	
27	1988	30,000	First Source Concentration Peak (Reported release)
28	1989	15,000	
29	1990	7,000	
30	1991	4,000	
31	1992	3,000	
32	1993	1,500	
33	1994	1,000	
34	1995	1,000	
35	1996	1,000	
36	1997	1,000	
37	1998	1,000	
38	1999	1,000	
39	2000	750	
40	2001	750	
41	2002	500	
42	2003	500	
43	2004	16,000	Second Source Concentration Peak (PCE Detected in
44	2005	6,500	OMW-2 at 16,000 µg/L in 2004)
45	2006	4,000	
46	2007	2,500	
47	2008	1,500	
48	2009	1,000	
49	2010	750	
50	2011	500	
51	2012	0	

Chemical Biodegradation Rates: Effect the extents of the PCE plume and TCE plume by dictating how rapidly these contaminants decay within the groundwater model study area. TCE biodegradation rates that were too high resulted in DCE plumes with concentrations of several hundred µg/L within the groundwater model study area, which are well in excess of any historically observed concentrations for DCE isomers. PCE biodegradation rates that were too low resulted in a PCE plume with concentrations of several hundred µg/L at the biodegradable site which are far higher than any historically observed PCE concentrations within monitoring wells in the vicinity of that site. Changing PCE and TCE biodegradation rates had a minor effect on the overall extents of the CAH plume.

Time Specific Source Concentration: Time specific source concentration has the greatest effect on the overall extent of the CAH plume, when all other parameters are held constant. Specifically, increasing PCE source concentrations had a great effect on the extent of the 1,000 and 100 µg/L PCE and TCE contours within the groundwater model study area but had a more limited effect on the extent of 1 µg/L contours.

Adsorption: As discussed in Section 3.2.4 contaminant sorption was considered as a model input parameter for PCE, TCE and DCE based on published octanol partitioning coefficients (koc) (EPA, 1996) and estimated organic carbon fractions in soil (foc). Contaminant adsorption, using foc values of 0.001 and higher had a profound effect on the overall extents of the CAH plume. Model simulations run with sorption programed only for PCE resulted in a PCE plume that did not extend to the Biodegradable Site until after 2002. PCE was detected at trace concentrations at BA6-MW20 by 1998. This value for PCE adsorption or higher caused temporal concentration peaks to occur too late in the groundwater model. Similarly, programming sorption values for TCE and DCE, based on the same published values, resulted in CAH plumes that did not extend as far downgradient within the groundwater model study area as is the case with observed groundwater monitoring results.

RT3D simulates adsorption by assigning a fixed or variable value within each grid cell based on a user defined isotherm curve. This adsorption value is used to calculate retardation for contaminants within the entire grid cell on a uniform basis. Detailed plume CAH plume studies have shown that contaminant transport and sorption does not occur on a uniform basis within an aquifer. CAHs become sequestered within low hydraulic conductivity (K) zones adjacent to high K zones where material transport occurs (FRTR, 2013). Sorption does not limit the plume velocity of the contaminant plume within the high K zones, as would be simulated in the RT3D model, but reduces the CAH plume concentration at distance from the source due to contaminant diffusion into adjacent low K zones.

Running the groundwater model within the groundwater model study area without adsorption resulted in overall CAH plume extents that approximated the extents observed in groundwater monitoring that were

discussed in Section 2.6, but did not match the PCE plume concentrations within the immediate vicinity of the Ballard Property. Higher assigned values for PCE and TCE sorption, resulted in PCE plumes that more accurately matched the observed PCE plumes in the vicinity of the Ballard Site but did not extend into the Biodegradable Site to the extent that has been observed in groundwater monitoring. These differences are discussed in further detail in section 5.

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5. MODEL RESULTS

Ground water fate and transport modeling results are presented in this section. The groundwater flow model and dissolved contaminant fate and transport model were run using site specific input parameters determined based on observed and published geologic and hydrologic data within the study area, observed contaminant distribution in groundwater, and model calibrations (Section 4). The following subsections present the model output processing requirements and model results.

5.1 Model Output and Data Processing

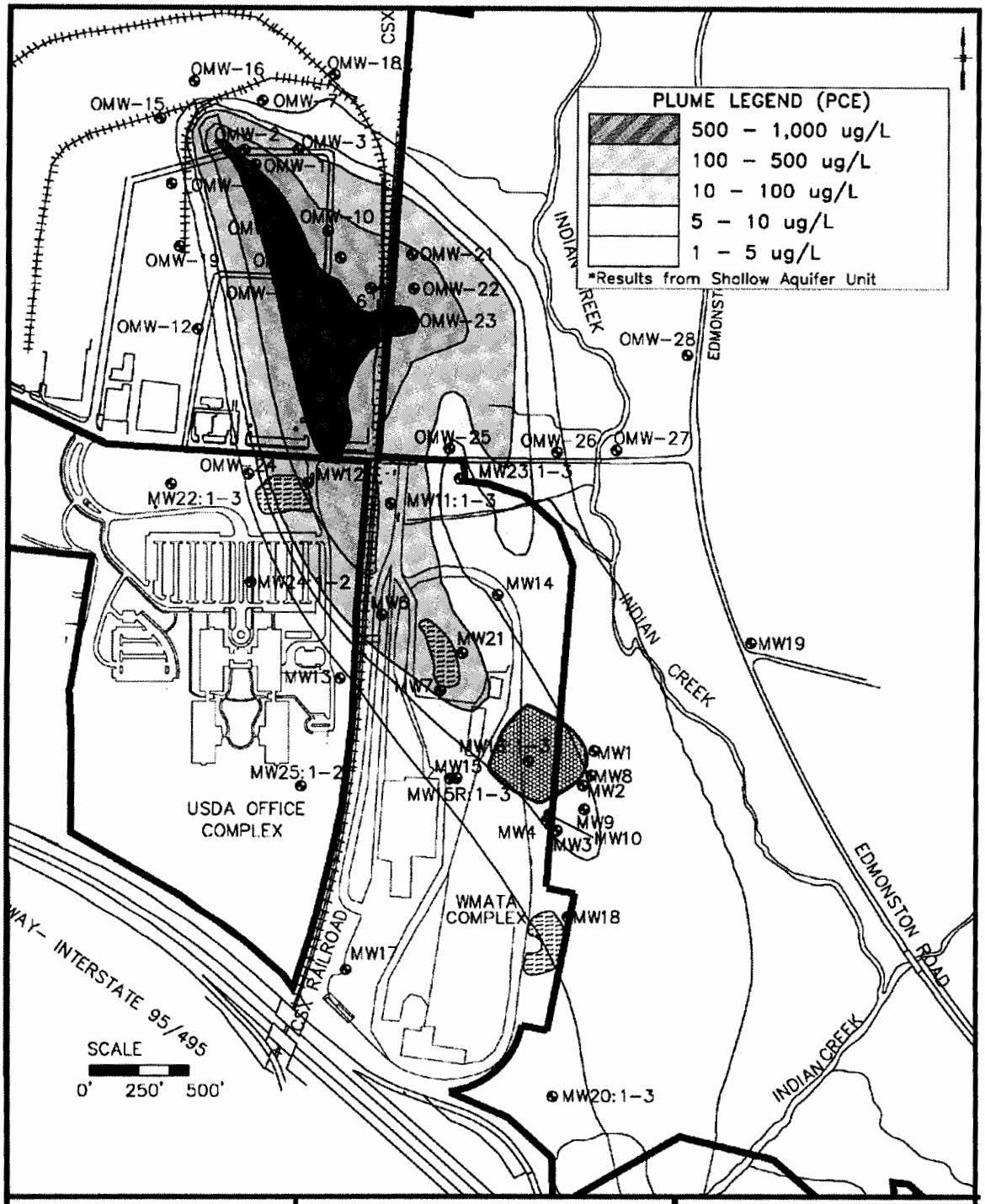
MODFLOW and RT3D calculate hydraulic potential and contaminant concentrations within each grid cell for each time step of the model simulations. RT3D model outputs consist of a single concentration of a specific contaminant (PCE, TCE or DCE) within each grid cell for each time period of the model simulation. Model simulation contaminant plume maps were created by exporting the RT3D model outputs for the relevant model simulation year into a contouring program to produce isoconcentration contours. The computer model begins the simulation in 1962 and ran through 2059. RT3D model outputs for Layer 1 and Layer 2 were very similar throughout the lateral extents of model grid, so all plume results for the shallow aquifer unit were derived from the RT3D model outputs for Layer 1. This matches the general patterns observed within the Groundwater Model Study Area where CAHs have been detected throughout saturated zone of the shallow aquifer unit. Layer 4 represents the deep aquifer unit.

5.2 Model Results

Final groundwater model input parameters were derived from the model calibration discussed in Section 4. Model output was compared against groundwater monitoring data that has been collected around the Biodegradable Site since 1991 and from off-site monitoring wells in the vicinity of the Ballard Site since 2002. Plume maps were derived from RT3D model outputs for the years 2004, 2010 and 2014 for comparison with plume maps that were generated from field data collected from Groundwater Model Study Area monitoring wells during the same time periods.

5.2.1 RT3D Model Results for the Year 2010

The first Groundwater Model Study wide joint sampling event was conducted during the summer of 2010 that included a contemporaneous well gauging event and a groundwater collection program on all Biodegradable Site, and Ballard Off-site monitoring wells. Groundwater model results from Layer 1 for PCE, TCE and DCE respectively for the model simulation year 2010, are presented in Figures 5.1, 5.2 and 5.3. Figures 5.1 and 5.2 can be compared against PCE and TCE plume maps that were produced from groundwater monitoring data that was collected during the joint sampling program in 2010 that are presented in Figures 2.8 and 2.9.


PLUME LEGEND (PCE)
500 – 1,000 ug/L
100 – 500 ug/L
10 – 100 ug/L
5 – 10 ug/L
1 – 5 ug/L
*Results from Shallow Aquifer Unit
CSX
INDIAN CREEK
EDMONSTON
OMW-16
OMW-18
OMW-15
OMW-2
OMW-3
OMW-1
OMW-10
OMW-19
OMW-21
OMW-22
OMW-23
OMW-12
OMW-28
OMW-25
OMW-26
OMW-27
MW12
MW23:1-3
MW22:1-3
MW11:1-3
MW24:1-2
MW14
MW8
MW21
MW19
MW13
MW7
MW25:1-2
MW15
MW1
MW8
MW2
MW15R:1-3
MW9
MW10
MW4
MW3
USDA OFFICE COMPLEX
WMATA COMPLEX
MW18
MW17
CSX RAILROAD
WAY– INTERSTATE 95/495
EDMONSTON ROAD
INDIAN CREEK
MW20:1-3
SCALE
0' 250' 500'
Figure 5.1.
PCE Isoconcentration contour map from 2010 Groundwater RT3D Model Output
BMT Designers & Planners
LEGEND
BARC6
BARC Boundary
Road
Creek
Building
Rail Road
Storm Water Retention Pond
Monitoring Well
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495
Miles

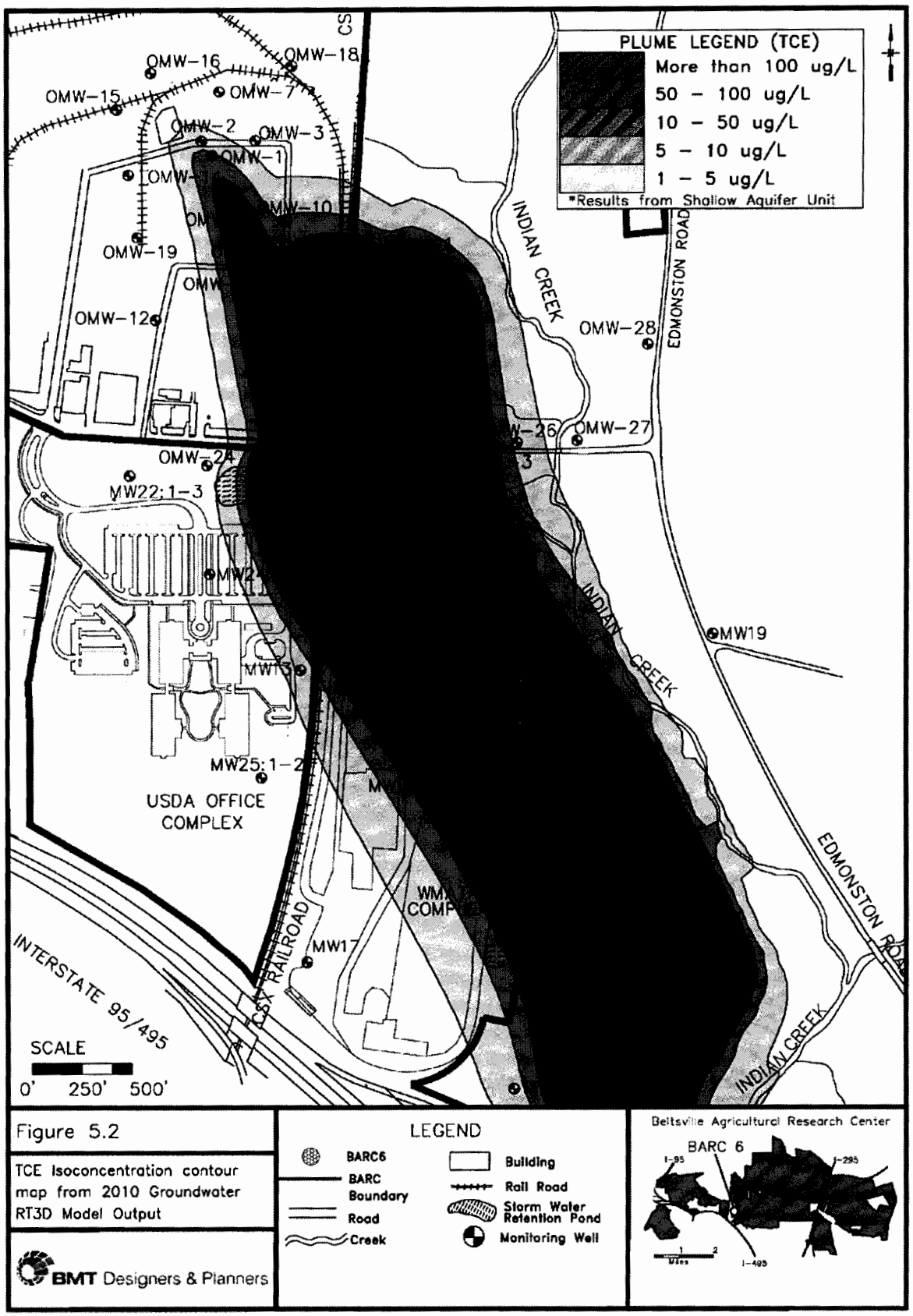


Figure 5.2

TCE Isoconcentration contour map from 2010 Groundwater RT3D Model Output

BMT Designers & Planners

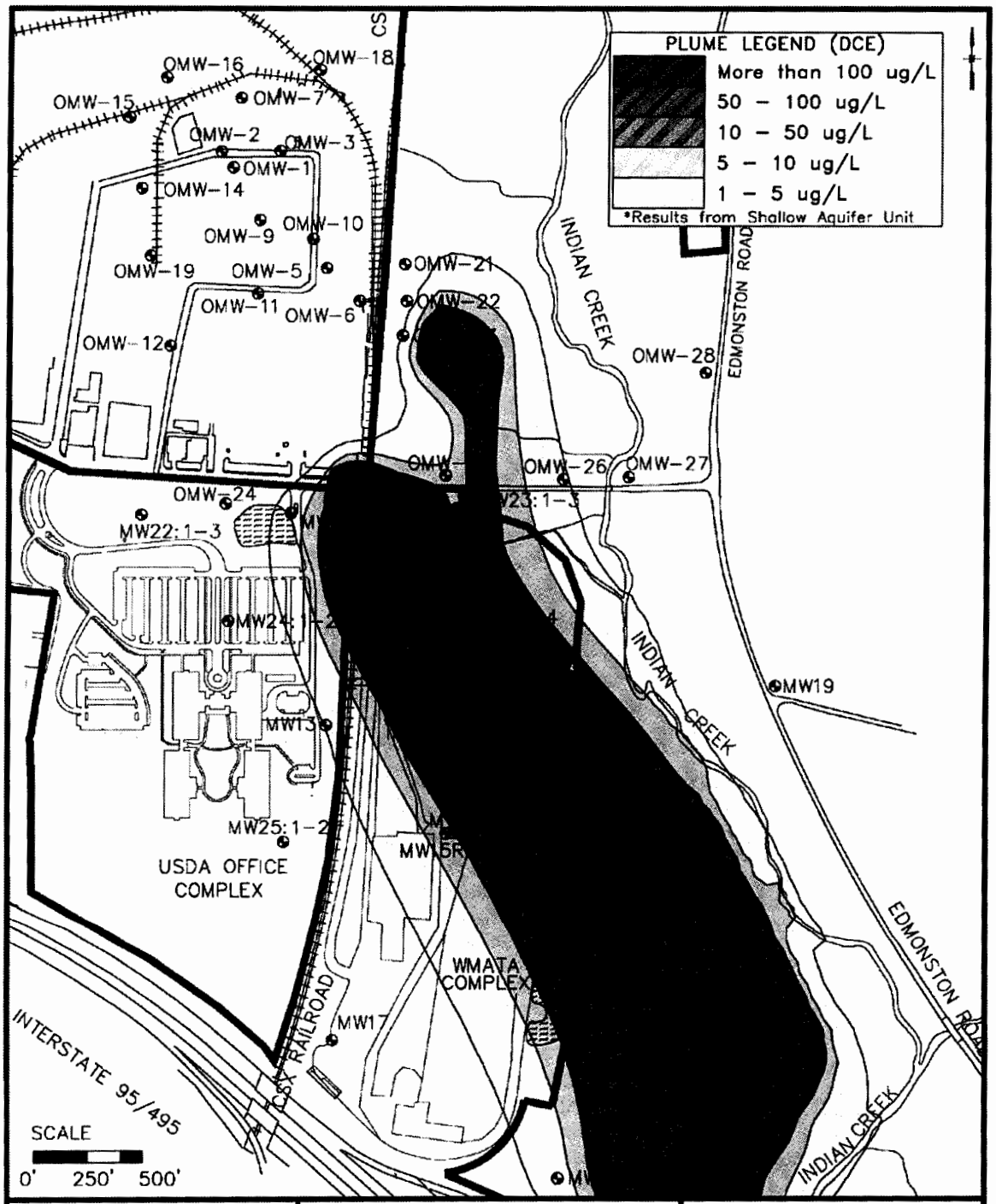


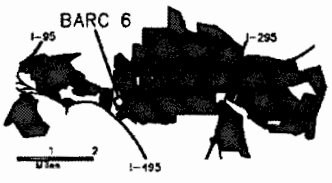
Figure 5.3

DCE Isoconcentration contour map from 2010 Groundwater RT3D Model Output

BMT Designers & Planners

LEGEND

- BARC6
- BARC Boundary
- Road
- Creek
- Building
- Rail Road
- Storm Water Retention Pond
- Monitoring Well



5.2.2 RT3D Model Results for the Year 2004

The highest recorded PCE concentration within the Groundwater Model Study area was detected in 2004 at OMW-2 at 16,000 µg/L. Figure 5.4 is a PCE plume map derived from groundwater quality data from sampling events that were conducted in February and March of 2004 within the groundwater model study area. Figure 5.5 is a PCE Plume map derived from the results from the GW Model in the simulation year of 2004.

5.2.3 RT3D Model Results for the Year 2014

The most recent joint sampling event within the groundwater model study area was conducted in early 2014. In 2014, measured PCE concentrations within OMW-2 were far lower (210 µg/L) than in OMWs located further downgradient such as: OMW-1 (990 µg/L), OMW-9R (670 µg/L) and OMW-10R (1,400 µg/L). This suggests that the PCE source at Ballard may be have been largely removed or exhausted by 2014. Figures 5.6 and 5.7 present the PCE plumes derived from a 2014 joint groundwater monitoring event from the groundwater model in the simulation year of 2014.

5.2.4 Modeling Results Discussion

In general, the groundwater model predicts CAH plumes that extend further east than has been observed during groundwater monitoring, and predicts a more uniform concentration of CAHs than is observed from actual sampling.

The groundwater model predicts the general direction that contamination migrates towards the Biodegradable Site, and the pattern of contaminants migrating east from the source, and then migrating south along the boundary between the Beltsville Industrial Park and the Indian Creek Stream Bed. The groundwater model predicts that PCE will rapidly degrade into TCE within biodegradation zone 2 (Figure 4.4), creating a zone of higher TCE concentration (100+ µg/L) situated around Sunnyside Avenue, with TCE concentrations towards the Biodegradable Site, and another zone of higher TCE concentration situated just east of the CSX railroad tracks where the slow movement of the PCE plume within the Indian Creek stream bed results in increasing TCE concentrations. Both of these patterns have been observed from groundwater monitoring within the groundwater model study area.

The highest recorded concentrations of TCE within the groundwater model study area were recorded in BA6-MW12 (244 µg/L) and BA6-MW13 (200 µg/L) and OMW-22 (250 µg/L), matching the general zones of high TCE concentrations predicted by the groundwater model. The groundwater model predicts that TCE will be present at concentrations of 30-50 µg/L in the vicinity of BA6-MW20, currently the furthest downgradient monitoring well, which matches observed plume results.

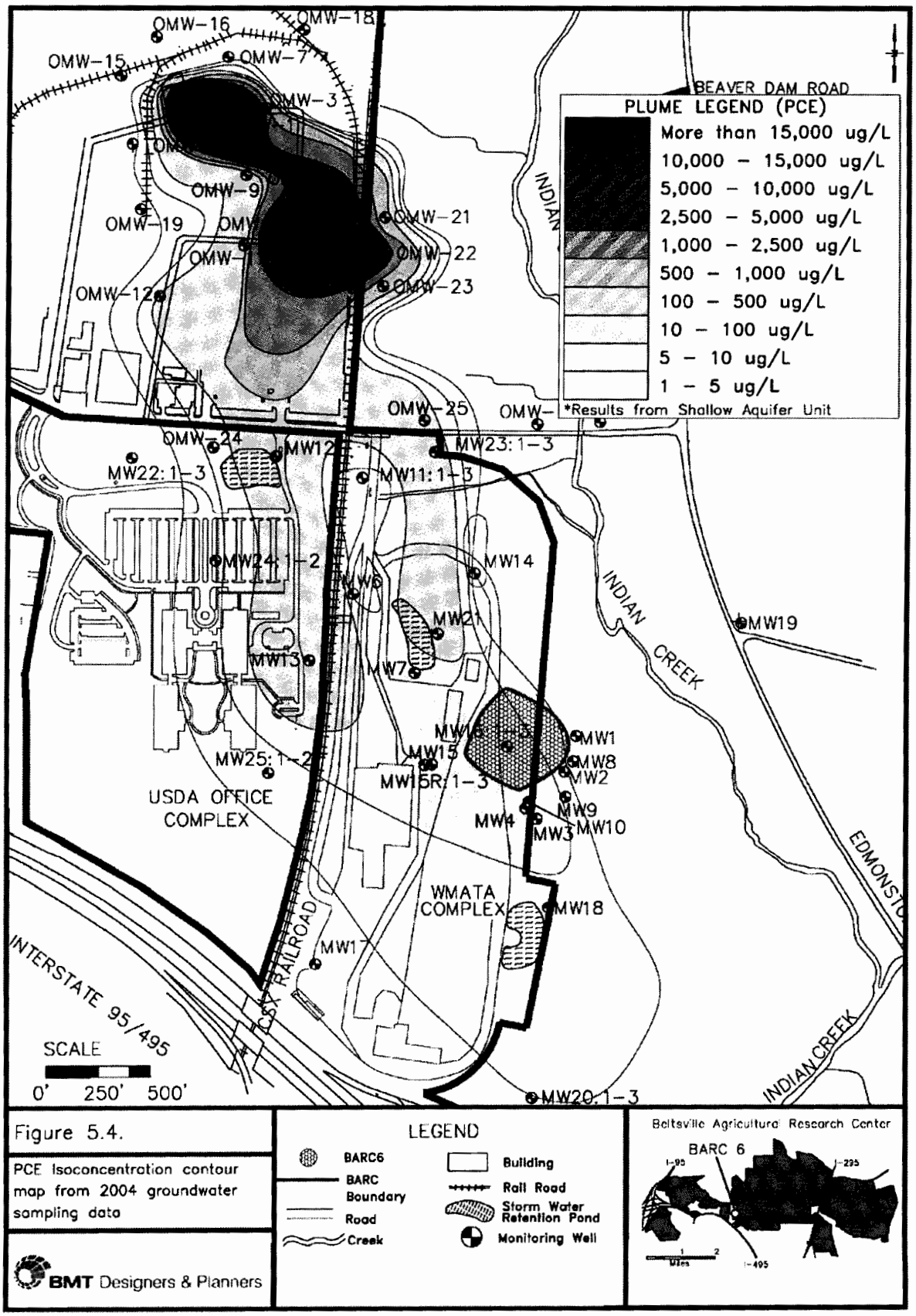


Figure 5.4.

PCE Isoconcentration contour map from 2004 groundwater sampling data

BMT Designers & Planners

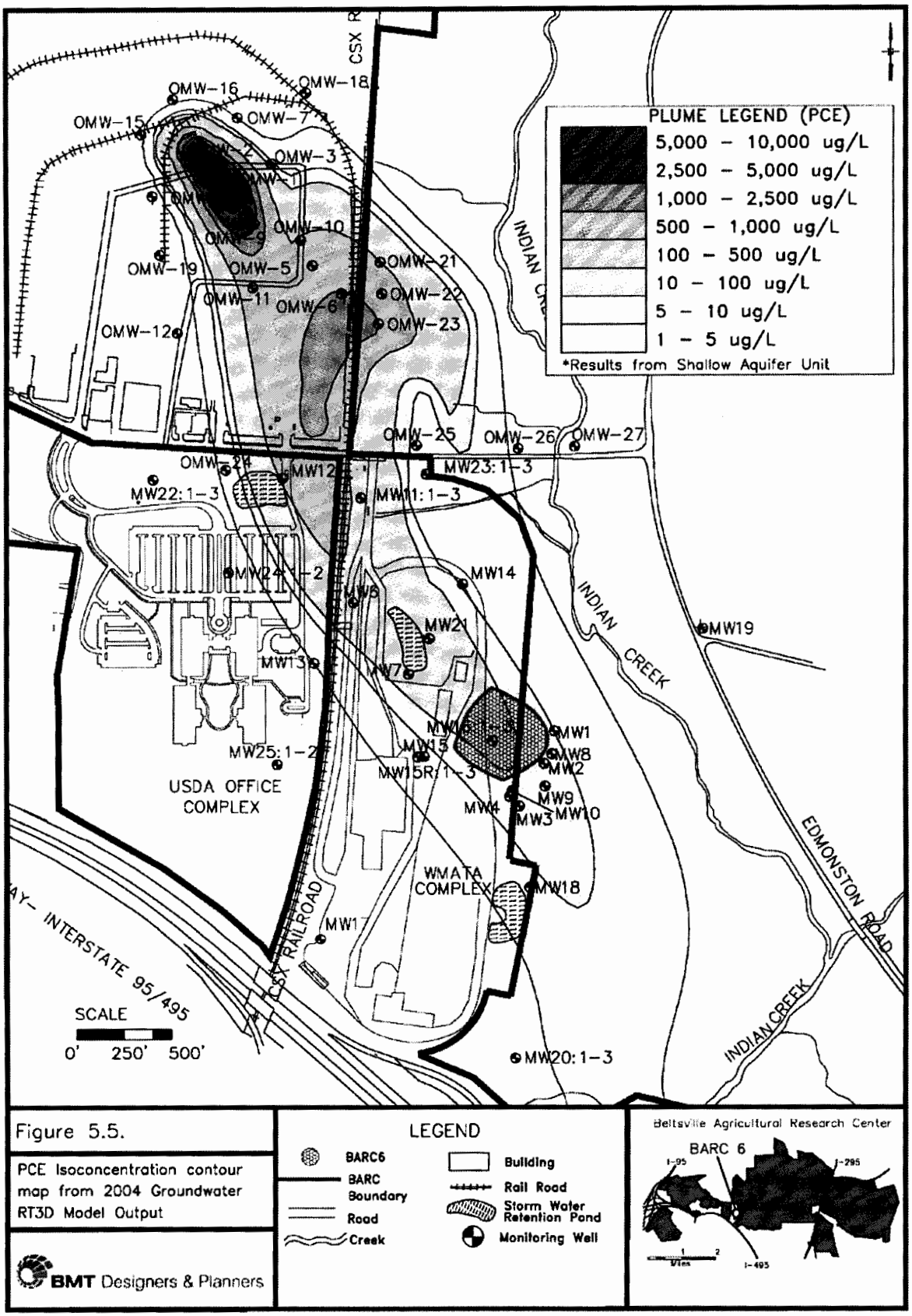
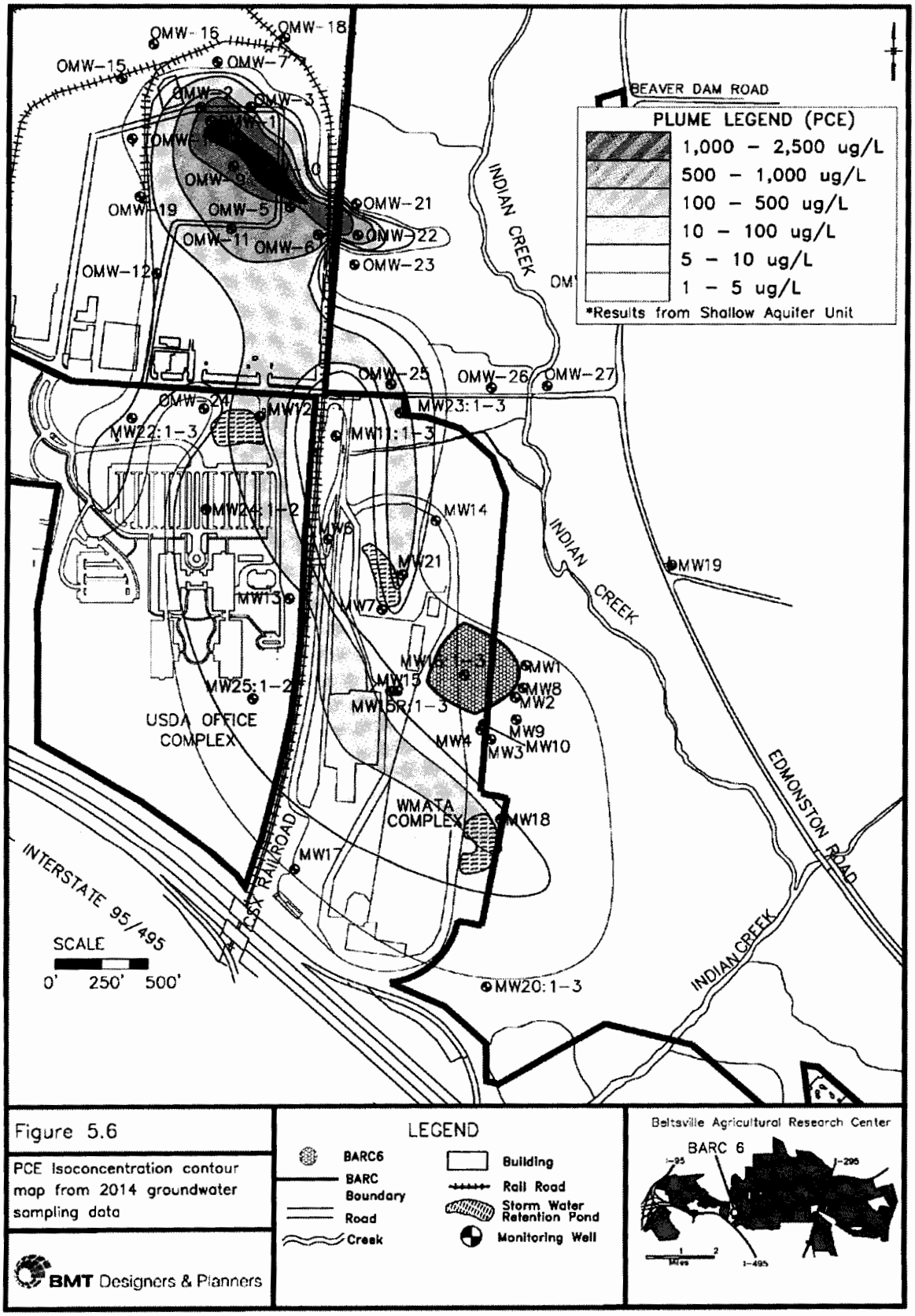
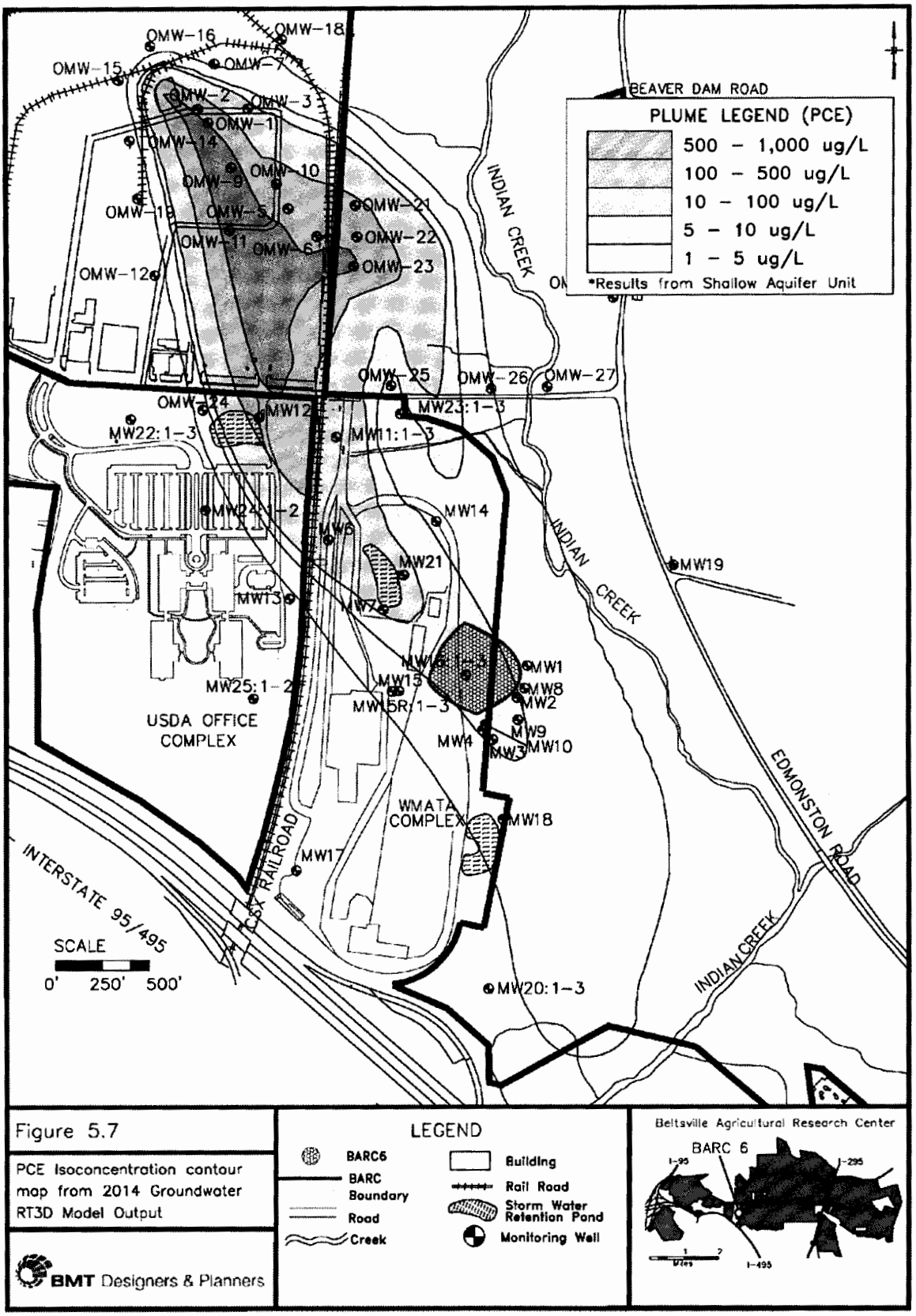


Figure 5.5.

PCE Isoconcentration contour map from 2004 Groundwater RT3D Model Output

BMT Designers & Planners


PLUME LEGEND (PCE)
1,000 – 2,500 ug/L
500 – 1,000 ug/L
100 – 500 ug/L
10 – 100 ug/L
5 – 10 ug/L
1 – 5 ug/L
*Results from Shallow Aquifer Unit
BEAVER DAM ROAD
INDIAN CREEK
EDMONSTON ROAD
INTERSTATE 95/495
CSX RAILROAD
USDA OFFICE COMPLEX
WMATA COMPLEX
SCALE
0' 250' 500'
OMW-15
OMW-16
OMW-18
OMW-7
OMW-19
OMW-12
OMW-21
OMW-22
OMW-23
OMW-25
OMW-26
OMW-27
MW22:1-3
MW23:1-3
MW11:1-3
MW24:1-2
MW14
MW21
MW19
MW13
MW7
MW25:1-2
MW15
MW15R:1-3
MW1
MW8
MW2
MW9
MW4
MW3
MW10
MW18
MW17
MW20:1-3
Figure 5.6
PCE Isoconcentration contour map from 2014 groundwater sampling data
BMT Designers & Planners
LEGEND
BARC6
BARC Boundary
Road
Creek
Building
Rail Road
Storm Water Retention Pond
Monitoring Well
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495
Miles


OMW-16
OMW-18
OMW-15
OMW-7
OMW-2
OMW-3
OMW-1
OMW-14
OMW-10
OMW-9
OMW-19
OMW-5
OMW-21
OMW-22
OMW-11
OMW-6
OMW-23
OMW-12
BEAVER DAM ROAD
PLUME LEGEND (PCE)
500 - 1,000 ug/L
100 - 500 ug/L
10 - 100 ug/L
5 - 10 ug/L
1 - 5 ug/L
*Results from Shallow Aquifer Unit
INDIAN CREEK
OMW-25
OMW-26
OMW-27
OMW-24
MW12
MW23:1-3
MW22:1-3
MW11:1-3
MW24:1-2
MW14
MW5
MW21
MW19
MW13
MW7
MW25:1-2
MW15
MW1
MW8
MW2
MW15R:1-3
MW9
MW4
MW3
MW10
USDA OFFICE COMPLEX
WMATA COMPLEX
MW18
MW17
CSX RAILROAD
INTERSTATE 95/495
SCALE
0' 250' 500'
MW20:1-3
EDMONSTON ROAD
INDIAN CREEK
Figure 5.7
PCE Isoconcentration contour map from 2014 Groundwater RT3D Model Output
BMT Designers & Planners
LEGEND
BARC6
BARC Boundary
Road
Creek
Building
Rail Road
Storm Water Retention Pond
Monitoring Well
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495

The groundwater model predicts concentrations of DCE, which is composed primarily of 1,1-DCE in the vicinity of the Biodegradable Site, that are somewhat higher than observed concentrations at the site, specifically downgradient of the Biodegradable Site at BA6-MW20. The groundwater model predicts that the highest concentrations of DCE will be located proximate to wells that are located close to Sunnyside Avenue, and that concentrations of DCE will be less than concentrations of TCE throughout the groundwater model study area, which matches observed groundwater monitoring results. The highest recorded concentrations of 1,1-DCE, within the groundwater model study area, have been detected at BA6-MW12 (160 µg/L) and BA6-MW13 (100 µg/L) with decreasing concentrations further downgradient.

The RT3D model does not simulate contaminant sorption in the same manner that it has been observed to occur in groundwater systems, so the plume concentration patterns close to the PCE source are lower and the zone of high PCE concentration (500+ µg/L) extends somewhat further downgradient than groundwater model results would predict because PCE is likely adsorbing into low K formations that are within or adjacent to high K formations within the preferential pathways. This effect is less pronounced at lower contaminant concentrations, so groundwater model results are more accurate at increasing distances downgradient from the PCE source.

5.3 Plume Extents Projections to the Year 2059

After the model calibration process had been completed, further groundwater model simulations were conducted to analyze groundwater plume trends for forty-nine (49) years after the first joint sampling event in 2010. PCE concentrations within OMW-2 were very low in 2012 (34 µg/L) and in 2014 (210 µg/L), suggesting that the PCE source at the Ballard Property had been largely removed and/or exhausted by that point. Based on this data, the groundwater model was programed with a PCE source concentration of 0 for the model years of 2012 through 2059.

Figures 5.8, 5.9 and 5.10 show the predicted PCE, TCE and DCE plumes from running the groundwater model to the year 2059, assuming a source concentration of 0 starting in the model year of 2011. The groundwater model predicts that PCE and TCE will not be present within the groundwater model study at concentrations above their Safe Water Drinking Act (SWDA) maximum contaminant levels (MCL) of 5 µg/L. The groundwater model predicts that isomers of DCE will persist within the groundwater model study area for the greatest length of time after the effective removal of the upgradient PCE source.

Groundwater model study area site heterogeneity suggests that some pockets of CAHs will remain in groundwater in 2059. These localized areas where CAHs adsorb into low conductivity soils, where they can remain as localized contaminant sources. Nevertheless, the model does suggest that CAH contamination around the Biodegradable Site will decrease to low concentrations over the next 40 to 50 years, assuming the successful elimination of the upgradient PCE source.

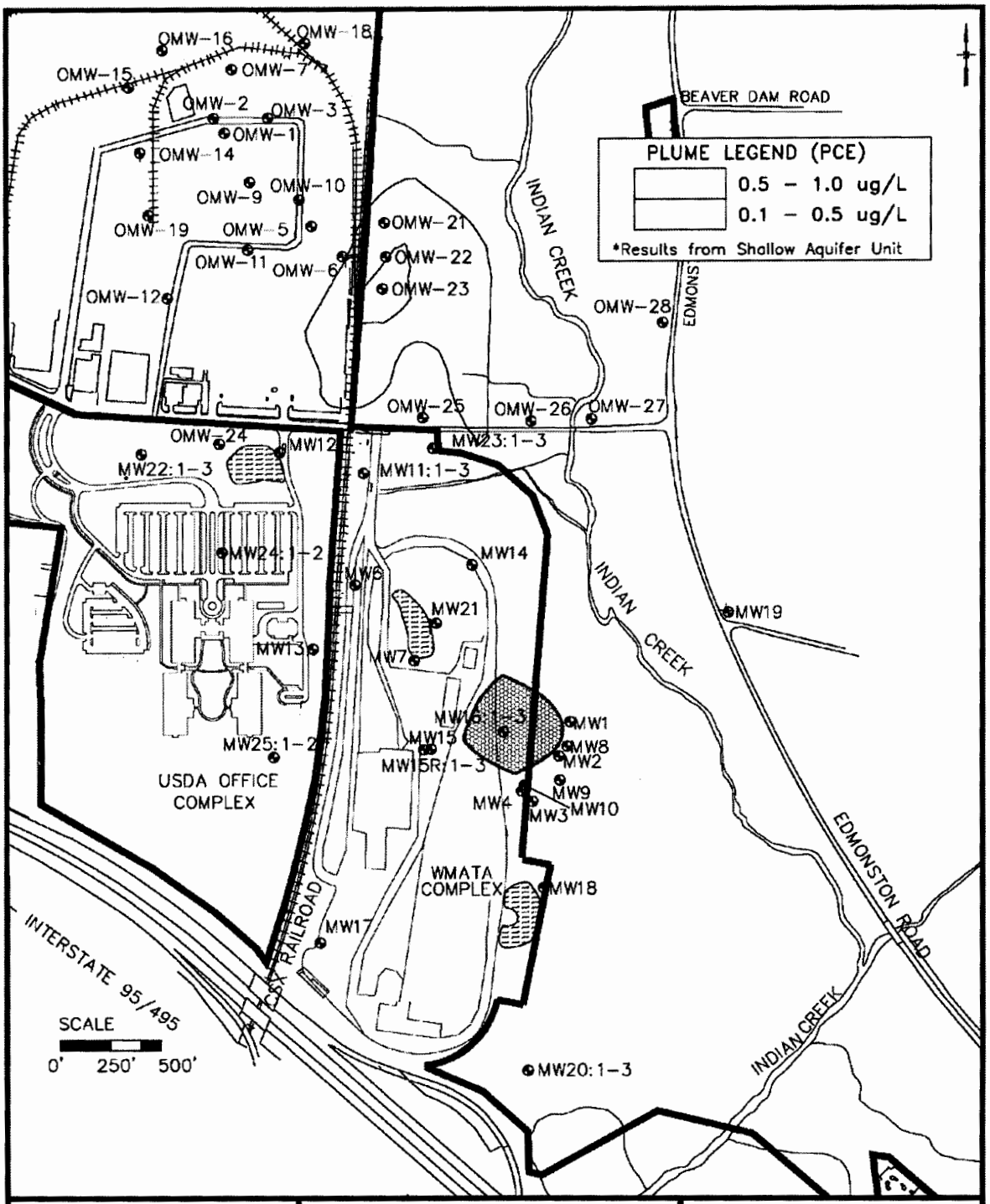


Figure 5.8

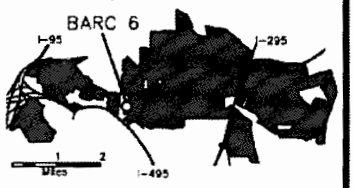
PCE Isoconcentration contour map from 2059 Groundwater RT3D Model Output

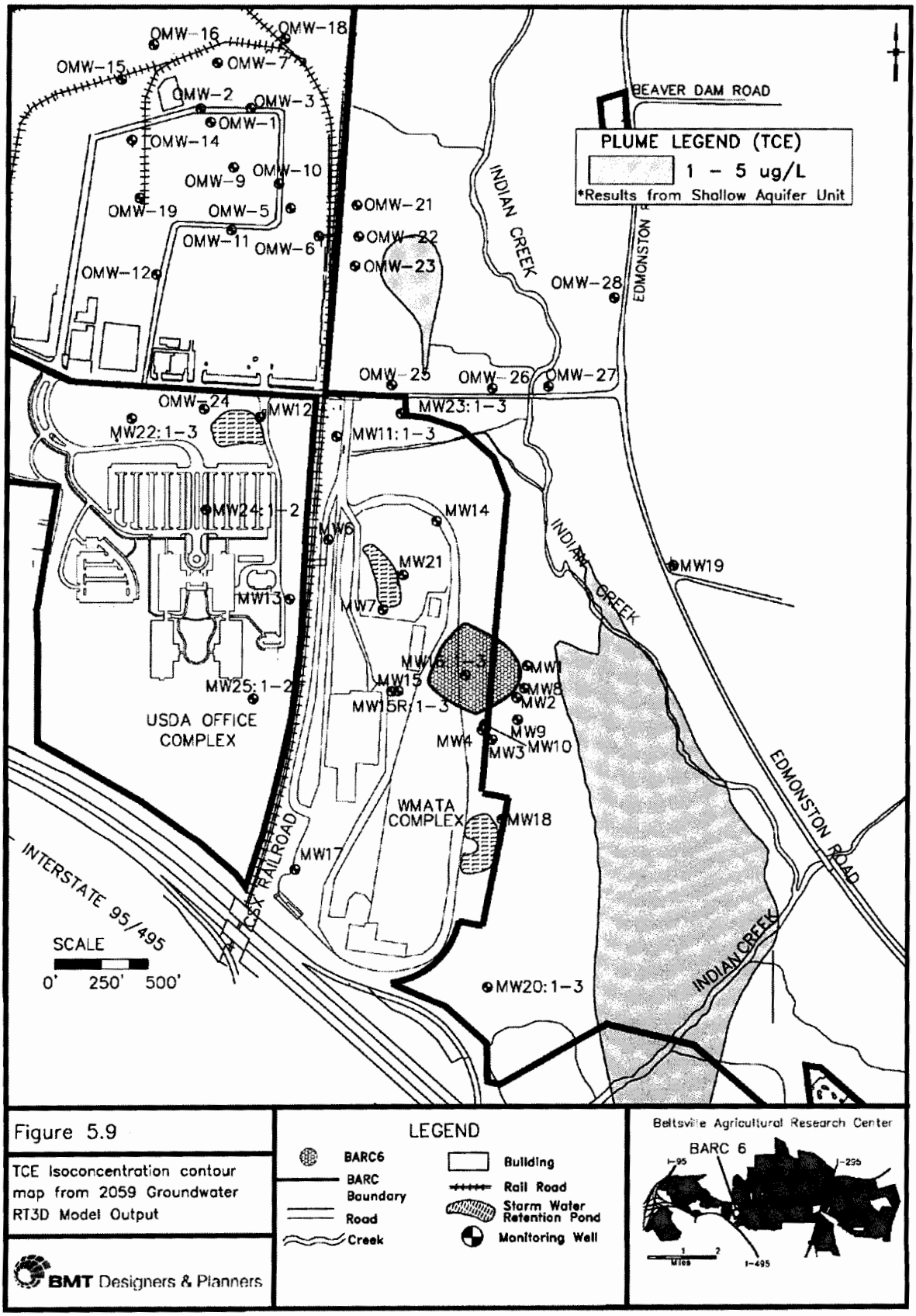
BMT Designers & Planners

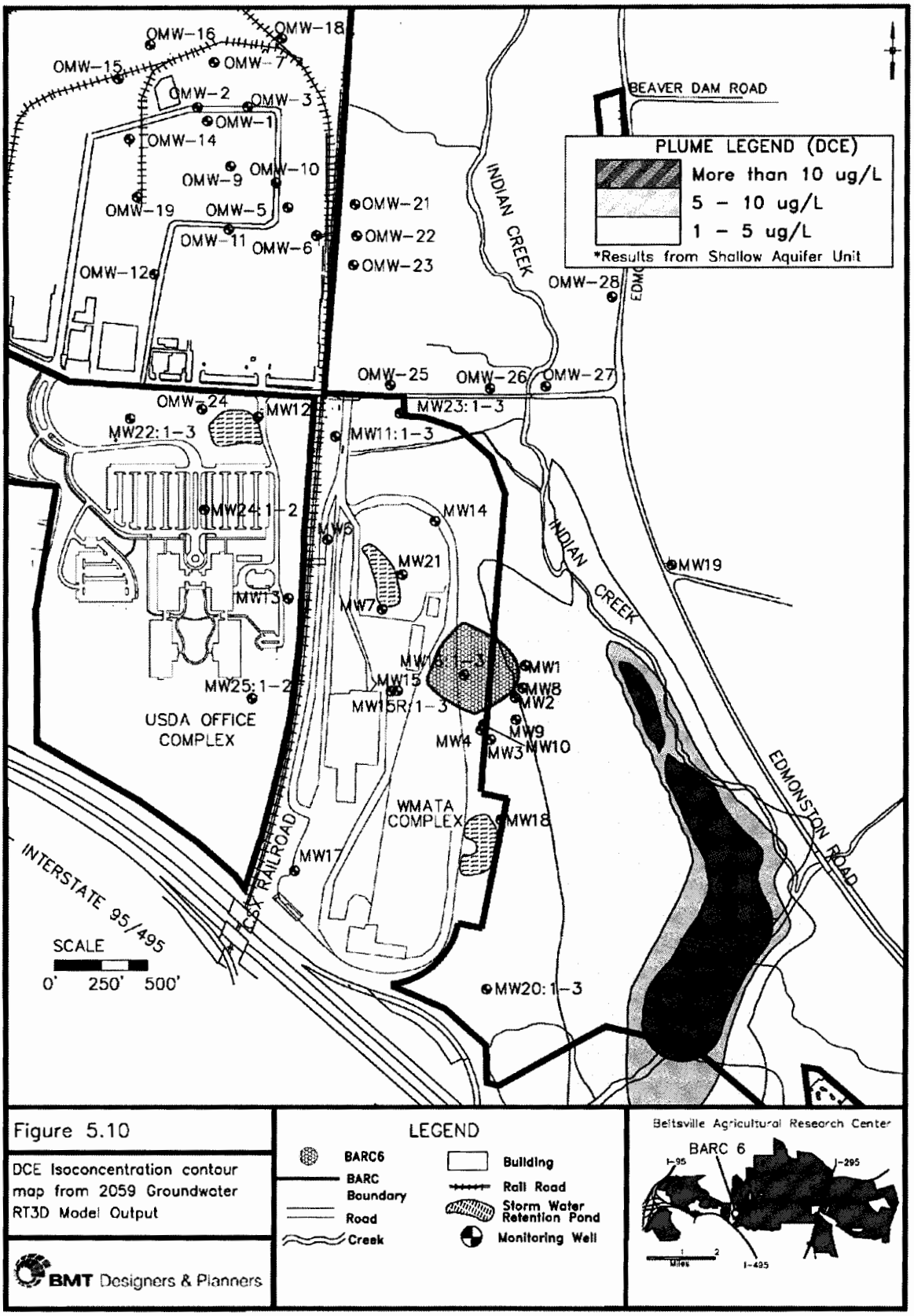
LEGEND

- BARC6
- BARC Boundary
- Road
- Creek
- Building
- Rail Road
- Storm Water Retention Pond
- Monitoring Well

Beltsville Agricultural Research Center




OMW-16
OMW-18
OMW-15
OMW-7
OMW-2
OMW-3
OMW-1
OMW-14
OMW-9
OMW-10
OMW-19
OMW-5
OMW-11
OMW-6
OMW-12
OMW-21
OMW-22
OMW-23
OMW-28
OMW-25
OMW-26
OMW-27
OMW-24
MW12
MW22:1-3
MW23:1-3
MW11:1-3
MW24:1-2
MW14
MW6
MW21
MW19
MW13
MW7
MW16:1-3
MW1
MW15
MW8
MW2
MW25:1-2
MW15R:1-3
MW9
MW4
MW3
MW10
MW18
MW17
MW20:1-3
BEAVER DAM ROAD
INDIAN CREEK
EDMONSTON RD
EDMONSTON ROAD
PLUME LEGEND (TCE)
1 - 5 ug/L
*Results from Shallow Aquifer Unit
USDA OFFICE COMPLEX
WMATA COMPLEX
CSX RAILROAD
INTERSTATE 95/495
SCALE
0' 250' 500'
Figure 5.9
TCE Isoconcentration contour map from 2059 Groundwater RT3D Model Output
BMT Designers & Planners
LEGEND
BARC6
BARC Boundary
Road
Creek
Building
Rail Road
Storm Water Retention Pond
Monitoring Well
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495
Miles


OMW-16
OMW-18
OMW-15
OMW-7
OMW-2
OMW-3
OMW-1
OMW-14
OMW-9
OMW-10
OMW-19
OMW-5
OMW-11
OMW-6
OMW-12
OMW-21
OMW-22
OMW-23
BEAVER DAM ROAD
INDIAN CREEK
PLUME LEGEND (DCE)
More than 10 ug/L
5 - 10 ug/L
1 - 5 ug/L
*Results from Shallow Aquifer Unit
OMW-28
OMW-25
OMW-26
OMW-27
OMW-24
MW12
MW22:1-3
MW23:1-3
MW11:1-3
MW24:1-2
MW14
MW6
MW21
MW19
MW13
MW7
MW5:1-3
MW1
MW15
MW8
MW25:1-2
MW15R:1-3
MW2
USDA OFFICE COMPLEX
MW9
MW4
MW3
MW10
WMATA COMPLEX
MW18
MW17
INTERSTATE 95/495
CSX RAILROAD
EDMONSTON ROAD
SCALE
0' 250' 500'
MW20:1-3
Figure 5.10
DCE Isoconcentration contour map from 2059 Groundwater RT3D Model Output
BMT Designers & Planners
LEGEND
BARC6
BARC Boundary
Road
Creek
Building
Rail Road
Storm Water Retention Pond
Monitoring Well
Beltsville Agricultural Research Center
BARC 6
I-95
I-295
I-495
Miles

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6. DISCUSSION AND SUMMARY

The purpose of this study was to examine subsurface hydrogeologic conditions and characteristics, and the full record of groundwater data produced from the Biodegradable Site and Ballard investigations to determine likely origins of observed groundwater contamination. While this study has focused on groundwater fate and transport modelling, supplemental information has also been identified that provides additional information that helps clarify hypotheses regarding potential sources. These data provide ample evidence that support a hypothesis that a source upgradient of the Biodegradable Site is responsible for groundwater contamination throughout the study area. A summary discussion of the modelling results and other supporting data is provided in the sections below.

6.1 Computer Simulation Modelling

A comprehensive, multi-species, biodegradation reaction model was developed for simulating fate and transport processes occurring within the Biodegradable Site Groundwater Model Study Area. The model was integrated within the numerical framework of the reactive transport code RT3D and groundwater flow simulation model MODFLOW. The integrated model is a useful tool for simulating the fate and transport of chlorinated solvents in saturated groundwater systems. The numerical model allows for the simulation of simultaneously occurring aerobic and anaerobic biological degradation processes. The model was designed to be general enough to describe spatial variations in reaction patterns to describe aerobic and anaerobic reaction zones.

As discussed in Section 1, this computer model was based on more detailed and extensive site data than the groundwater model developed for the initial draft of the RI in 2004. That model was developed to predict potential patterns for future site contamination in the vicinity of the Biodegradable Site under a number of possible scenarios based on known site conditions at the time. The purpose of this effort was to simulate historical site data with a simplified conceptual model to examine mechanisms that drive contaminant plume migration within the groundwater model study area. While the reactive transport model does not capture all localized variations in contaminant concentrations, the iterative development process to produce the model provides a useful framework for integrating site geological, hydrological and chemical data. The conceptual model of the groundwater model study in this report can serve as the basis for more detailed computer models and for future predictions of contaminant plumes in the vicinity of the Biodegradable Site.

The flow and transport model was calibrated to reflect the field conditions observed at the site and historical data collected within the groundwater model study area over the course of the numerous investigations conducted at the site. Calibration involved matching model predicted CAH plume extents and concentrations against observed historical groundwater monitoring data to estimate the spatial extents of the CAH plume over time. The model successfully re-created the flow conditions observed at

the site. In addition, the concentration and distribution of PCE, TCE, and DCE plumes predicted by the model provided reasonable estimates of observed data from more than a decade of continuous groundwater quality monitoring.

Sensitivity analysis was completed to develop an understanding of how the model is affected by changes to model input parameters. Preliminary screening simulations indicated that the horizontal hydraulic conductivity was the most critical MODFLOW model parameter that affects CAH plume migration patterns. The degradation rates of PCE and TCE, and time-specific source concentrations were the two most critical model RT3D model parameters that affected the extents and distribution of the PCE, TCE and DCE plumes. Further analysis of the model results indicated that the spatial extents of overall CAH contamination is most sensitive to hydraulic conductivity and least sensitive to source loading rates, whereas the total concentrations within CAH plumes are most sensitive to the decay rates and least sensitive to changes in hydraulic conductivity.

Considering the heterogeneity and complexity of the study area, the model should be considered as an initial effort to simulate a complex multi-species transport system. Additional work could be completed to further improve the predictive capability of the model. Nevertheless, the model description developed in this study provides results that closely match observed results, and provides a useful framework for integrating CAH degradation data collected within the study area. The results of the model simulations can be used for predicting future trends and migration of the CAH plumes under a series of scenarios involving PCE source concentrations within the Ballard Site. Model simulations that were run to the year 2059, predict that CAH plumes will continue to migrate further downgradient, but will have dissipated or degraded to levels that do not exceed currently regulated criteria in that time span.

The computer models discussed in this report were able to predict the approximate extents of the PCE, TCE and DCE plumes within the study area based on documented PCE releases at the Ballard Site and subsequent upgradient groundwater monitoring data that was conducted within, and in the vicinity of, that site. The computer model used physical, hydraulic and natural attenuation parameters that are within the range of published values for large plumes and on measured site conditions within the groundwater model study area.

Key conclusions from the modeling effort include:

- The modelling effort provides a reasonable mechanism to predict the migration of CAHs in the vicinity of the Biodegradable Site. Modelling results provide realistic estimates of CAH concentrations over time in the study area.

- Both observed data and modelling results reveal a pattern of contaminant migration within the study area is distinctly to the southeast toward the Biodegradable Site from an upgradient source. In addition, the areal extent of groundwater contamination is well established and has not varied significantly with over 15 years of monitoring.

- Modelling results are consistent with observed degradation patterns throughout the study area, and are consistent with movement of a PCE source moving to toward the Biodegradable Site, with corresponding increases in TCE and DCE concentrations moving downgradient over time.

- Based on the modelling, the source of CAH groundwater contamination observed at BARC 6 is located upgradient, and is very likely the Ballard facility, and not associated with the Biodegradable site. There is no reasonable model scenario under which groundwater contamination originating at BARC 6 could result in the concentrations observed over time north of the site.

6.2 Biodegradable Site Landfill Removal Action (1993-1994)

Extensive analytical testing was conducted for chlorinated solvents and VOCs during the Biodegradable Site Removal Action in 1993 during the course of excavation, dewatering, atmospheric screening and waste characterization. During this removal action, approximately 93,000 tons of soil and debris were removed. Removed soil and debris was replaced with clean fill. The records from this effort were examined in 2013, and a letter report prepared to evaluate the findings from the removal action that are included in Appendix E.

Major findings from the review included:

- Data produced as part of the landfill removal action failed to identify CAHs as a major component of the landfill contents. PCE was not detected in any of the soil samples collected within the area excavated, and TCE was detected only once, at trace concentrations at an elevation below the grade of the excavated wastes.

- The only medium to produce consistent detections for PCE was from influent water to the treatment system associated dewatering operations that lowered the water table beneath the site for excavation, and that also intercepted groundwater from upgradient offsite sources.

- PCE, TCE and isomers of DCE were detected in only one soil sample collected beneath the landfill waste. TCE and isomers of DCE were detected in one wetland sediment sample and PCE was not detected in shallow wetland soils adjacent to the Biodegradable Site.

- Chlorinated solvents were not detected in any waste drums that were recovered during the removal action and no VOCs were detected by Flame-Ionization Detectors (FID) or Photo-Ionization Detectors (PID) that were used for atmospheric monitoring (BMT, 2014).

- The results strongly suggest that PCE and TCE detected in groundwater during site dewatering were, and are, migrating from sources upgradient of the Biodegradable site. A potential upgradient source was not known at the time of the remediation effort; however, the Ballard site represents at least one major source that has experienced upgradient releases consistent with those detected at the Biodegradable site. These releases have been identified and fully characterized by BARC through investigations completed under the CERCLA Remedial Investigation process, and by the MDE through their voluntary cleanup programs.

6.3 Historical Data and Other Lines of Evidence

Groundwater and surface water monitoring has been conducted from 1997 to present day at the Biodegradable Site that includes a monitoring well network of 25 wells screened to a depth of up to 150 feet below ground surface (bgs). A total of 28 monitoring wells are associated with the Ballard site, and joint sampling has been conducted on 3 occasions to provide contemporaneous data sets. The most recent joint sampling event took place in 2014 and the report on that event which includes data and trend graphs dating to the origins of the Biodegradable site sampling in 1997 is provided in Appendix C.

Apart from the modelling effort and landfill removal action, there is additional evidence that has been produced from investigations that also support a hypothesis that the Biodegradable Site not responsible for observed groundwater contamination. These additional aspects are summarized below.

- Surface water sampling has been completed in conjunction with these sampling events associated with the Biodegradable Site. PCE has consistently been detected in surface water samples collected upgradient of the Biodegradable Site and high concentrations of TCE and isomers of DCE have consistently been detected in monitoring wells installed upgradient and side-gradient of the Biodegradable Site in a pattern that shows much higher concentrations in wells located closer to the Beltsville Industrial Park and further from the Biodegradable Site.

- Concentrations of PCE associated with the Ballard site were as high as 8,400 µg/L (OMW-10) roughly 1,000 feet dowgradient of the Ballard property. Conversely the highest concentration of PCE associated with the Biodegradable Site was 29 µg/L (BA6-MW-12), which is located 1,700 feet upgradient of the former landfill. Concentrations of TCE associated with the Ballard site were as high as 250 µg/L (OMW-22) roughly 1,300 feet dowgradient of the Ballard site; conversely the highest concentration of TCE associated with the Biodegradable Site was 280 µg/L (MW-12).

The highest PCE and TCE concentrations located in monitoring wells located downgradient of the Biodegradable Site have been detected in BA6-MW10 at 7.6 µg/L and 70 µg/L respectively. A clear concentration gradient of approximately an order of magnitude exists between the two sites.

- The spatial extent and concentration patterns of the CAH plumes in the vicinity of the Biodegradable Site have not changed substantially since the landfill Removal Action was completed in 1994.

- The assertion that the Biodegradable Site is not a likely source of PCE or TCE contamination in groundwater is also supported by several previous site investigations. PCE was detected at concentrations exceeding SDWA MCLs of 5 µg/L in six surface water samples collected in Indian Creek in sampling locations that are hydraulically upgradient of the Biodegradable Site (Ambient Water Quality Criteria [AWQC] for PCE is 0.69 µg/L). TCE and isomers of DCE were detected in monitoring wells installed proximate to the Biodegradable Site and in 2 monitoring wells (MW6 and MW7) that were installed several hundred feet upgradient of the Biodegradable Site (Apex, 1994). PCE was detected at concentrations of up to 25 µg/L from surface water sampling locations along Indian Creek hydraulically upgradient of the former Biodegradable Site during Phase II Environmental Investigations in 1992 that preceded the BARC 6 remediation program. No PCE or TCE were detected in surface water samples collected within Indian Creek at locations that are hydraulically upgradient of the Ballard Site (Apex, 1994).

- PCE and TCE were not detected within test pits that were advanced within wetland soils as part of the initial investigations of the Biodegradable Site in 1991/1992, and PCE and TCE were not detected within soil borings collected from the Biodegradable Site landfill soils

- The fact that TCE and Isomers of DCE were detected at higher concentrations than PCE whenever VOCs were detected in soils and groundwater in the vicinity of the Biodegradable Site strongly suggest an upgradient source that had released PCE to the environment a sufficient length of time prior to 1992 to allow for substantial breakdown of PCE into its' daughter products. The presence of PCE at high concentrations in upgradient surface water samples, collected from a gaining stream, provide additional evidence of a large upgradient PCE source.

6.4 Summary and Conclusions

The primary lines of evidence evaluated in this report provide compelling evidence that the Biodegradable Site is not responsible for the CAHs identified in groundwater at the site. Based on the results from these groundwater model simulations, data from over a decade of site investigations from monitoring wells at both the Biodegradable site and the Ballard site, and the results from the removal action at the

Biodegradable Site, it is unlikely that any observed PCE, TCE or DCE contamination in groundwater observed within the Groundwater Model Study Area originated at the Biodegradable Site.

Although much of the foregoing presentation and analysis within this report focus on the fate and transport modelling aspects associated with the site, investigations completed over the course of many years, and the newly acquired data from the landfill excavation (Appendix E) provide additional data that further supports a hypothesis that the Ballard site is the source of CAHs in groundwater identified in the vicinity of the BARC 6 site.

7. REFERENCES

Apex Environmental, Inc., 1991. *Preliminary Assessment/Site Investigation for the Beltsville Agricultural Research Center, Beltsville, Maryland,* May.

Apex, Inc., 1994. *Phase II Environmental Investigation for the Biodegradable Site at the Beltsville Agricultural Research Center,* August.

AEC, 2002. Revised Subsurface Investigation Work Plan - W.P. Ballard & Company of Washington, Inc., April 22.

AEC, 2008. *Off-Site Groundwater Delineation Investigation Implementation Report; W.P. Ballard & Company of Washington, Inc.* September.

BMT Entech, 2004. *Remedial Investigation Report: Biodegradable Site (BARC 6) (Draft Final),* July.

BMT Entech, 2006. *Feasibility Study Report: Biodegradable Site (BARC 6) (Draft),* January.

BMT, 2010. *BARC 6 (Biodegradable Landfill) After Action Report for the Installation of Supplemental Groundwater Monitoring Wells and Groundwater Characterization,* December.

BMT, 2012. *Letter Report - Biodegradable Landfill Site (BARC 6), April 2008 Groundwater Sampling Report.* July.

BMT, 2014. *Letter Report - Final Landfill Remediation Report for Landfill Remediation, Biodegradable Landfill (BARC 6) Appendix Scanning and Analysis.* October.

Clement et al, 1999 *Natural attenuation of chlorinated ethane compounds: model development and field-scale application at the Dover Site,* October 28.

ENTECH, Inc., 1997a. *Field Reconnaissance Report: Beltsville Agricultural Research Center*, January.

ENTECH, Inc., 1997b. *Aerial Photographic Site Analysis: Beltsville Agricultural Research Center,* January.

ENTECH, Inc., 1997c. *Desktop Collection Report: Beltsville Agricultural Research Center,* December.

EPA, 1993. *Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration.* September.

FRTR, 2013. *Federal Remediation Technologies Roundtable (FRTR) Presents: Large and Dilute Plumes, May.* http://www.clu-in.org/conf/tio/FRTRPresents_050113/

Gelhar et. al, 1992 *Gelhar, L. W., C. Welty, and K. R. Rehfeldt (1992), A critical review of data on field-scale dispersion in aquifers, Water Resources.*

Hemond, 2000 *Chemical Fate and Transport in the Environment, Second Edition. Academic Press.*

Kenoyer, 1988. *Tracer Test of Anisotropy in Hydraulic Conductivity of Granular Aquifers.* Groundwater Monitoring Report, Summer 1988.

KCI, 1994. *Hydrogeological Study of the Biodegradable Site, KCI Technologies.* May 6, 1994.

Lovanh et al., 2000 *Guidelines to Determine Site-Specific Parameters for Modeling the Fate and Transport of Monoaromatic Hydrocarbons in Groundwater.* October.

Mack, F.R., 1966. *Groundwater in Prince George's County, Bulletin 29, Maryland Geological Survey, Baltimore, Maryland.*

MDE, 2007. *Maryland Department of the Environmental order requiring an environmental response from the Ballard Company pursuant to the Maryaldn Hazardous Response Plan.* May 18, 2007.

Maryland Coastal Plain Aquifer Information System: *Maryland Coastal Plain Aquifer Information System: Hydrogeologic Framework. 2013, Andreasen, D.C., Staley, A.W., and Achmad, G.J. Open-File Report 12-02-20*

Miller, 2003. *Email to T. Fox (USDA-OGC) dated April 7. Subject: Briefing on conversation with Brian Dietz of MDE regarding the Ballard cleanup.*

NIST, 2000. *Factors Affecting Sorption of Organic Compounds in Natural Sorbent Water Systems and Sorption Coefficients for Selected Pollutants. A Review.* October. http://www.nist.gov/data/PDFfiles/jpcrd598.pdf

NOAA, 2012 *Eastern Region Headquarters precipitation summary at BWI 1871-2012:* http://www.erh.noaa.gov/lwx/climate/bwi/bwiprecip.txt.

Simcore Software, 2012. *Processing Modflow, An Integrated Modeling Environment for the Simulation of Groundwater Flow, Transport and Reactive Processes.* July.

U.S. Dept. HHS, 1997. *United States Department of Health and Human Services, Agency for Toxic Substances and Disease Registry Report on Tetrachloroethene,,* September.